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DESIGN OF A CIRCULATION CONTROL AIRFOIL MODEL FOR EVALUATION IN THE TRANSONIC WIND TUNNEL     CID-77-1

(12)

# DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084



## DESIGN OF A CIRCULATION CONTROL AIRFOIL MODEL FOR EVALUATION IN THE TRANSONIC WIND TUNNEL

by
Albert P. Clark



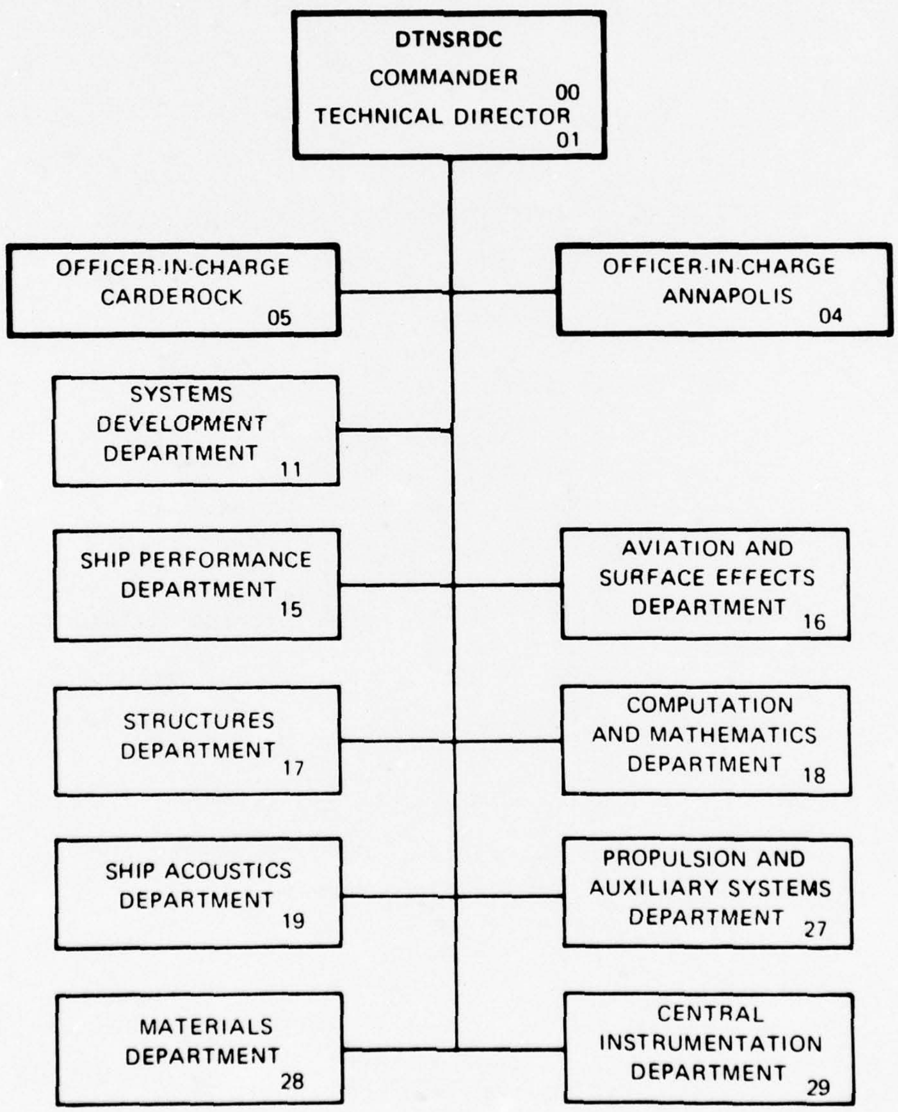
CENTRAL INSTRUMENTATION DEPARTMENT

DEPARTMENTAL REPORT



March 1977     CID-77-1

## MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)


A circulation control (CC) airfoil model able to withstand high aerodynamically induced loads and high internal pressure loads was designed, manufactured, and structurally evaluated. The CC airfoil, with a span approximately three times that of any CC model heretofore evaluated, successfully performed at air speeds up to Mach 0.8. And it was the first CC model evaluated in the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) Transonic


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Wind Tunnel. Structural and design problems encountered, their resolution, and salient features of the design are discussed.

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## ABSTRACT

A circulation control (CC) airfoil model able to withstand high aerodynamically induced loads and high internal pressure loads was designed, manufactured, and structurally evaluated. The CC airfoil, with a span approximately three times that of any CC model heretofore evaluated, successfully performed at air speeds up to Mach 0.8. And it was the first CC model evaluated in the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) Transonic Wind Tunnel. Structural and design problems encountered, their resolution, and salient features of the design are discussed.

## ADMINISTRATIVE INFORMATION

The experimental program, under which the work reported herein was performed, was funded by the Naval Air Systems Command (AIR-320D) under Task Area WSL06.001. The DTNSRDC Work Unit was 1619-200. This work was accomplished during the period January 1976 through June 1976.

## UNITS OF MEASUREMENTS

U. S. customary units are the primary units in this report. Metric units are given adjacent to the U. S. units in parentheses. Angular measurement is the only exception. The unit of degrees is not converted to radians.

## INTRODUCTION

The Design Engineering Division (Code 294) of the Central Instrumentation Department, DTNSRDC, was requested by the Rotary Wing Group (Code 1619) of the Aviation and Surface Effects Department, DTNSRDC, to design and have constructed an airfoil model required for evaluation in the Center's Transonic Wind Tunnel. The model was to be of rectangular planform with a 10 foot (3.05 m) span, 18 inch (0.457 m) chord, 0.16 thickness ratio, and section contour of circulation control (CC) Shape NCCR 1610-8042S. It was to have the capability of withstanding aerodynamic loads at airspeeds up to Mach 1 with pitch angles of -10 degrees to +6 degrees. Loading information as well as other requirements for the design were furnished by Code 1619 and are presented in the next section of this report.

Several design concepts were studied to determine which would best suit all the loading requirements without sacrificing structural integrity while simultaneously providing a smooth passage for the flow of internal air to the circulation control slot. Although secondary to the other requirements, the design concept was directed towards minimizing complexity of manufacture.

In the selected configuration (Figure 1) the foil was constructed entirely (with the exception of the bolts) of high strength aluminum. Two support struts, spaced 5 feet (1.52 m) apart about mid-span, were made of HY-80 steel.

## DESIGN SPECIFICATIONS

The following specified design requirements governed the general configuration geometry and mechanical features. The structural requirements, based on the anticipated loads, also significantly influenced the geometric configuration.

The model was to be rectangular in planform with a 10 foot (3.05 m) span, 18 inch (0.457 m) chord, 0.16 thickness ratio and outer section contour of CC shape NCCR 1610-8042S. The upper and lower trailing edge sections were to be detachable. Accommodation for ducting 17 psig (117 KPa) air with a 3 lb/sec (1.36Kg/s) flow rate within the airfoil was to be provided. Air entrance into the ducting was to be from both ends of the airfoil, and the air passage from the entrance through the airfoil to the exit slot was to be as smooth and unrestricted as possible. The exit air slot opening was to be nominally 0.030 inches (0.762 mm) and adjustable. The duct cross-sectional area was to be no less than 11 $in^2$ (71 $cm^2$) throughout. The model was also to contain 108 pressure taps at specified locations on the surface of the airfoil, with tube lines leading to external measuring instrumentation. The model was to be operated at pitch angles from -10 degrees to +6 degrees.

The following load data specified by Code 1619 were:

Lift load +840 $lb/ft^2$ (40.2 KPa)
-660 $lb/ft^2$ (-31.6 KPa)

Total moment about the 45 percent chord;

1800 ft-lb (2.4 KN.m) at +6 degrees angle of attack
-3375 ft-lb (-4.6 KN.m) at -10 degrees angle of attack

Stress Limit: A factor of safety of four based on the yield strength of the material.

## APPROACH

### DESIGN

#### Conceptual Design Stage

The first design concept considered was to construct the model in the manner that many smaller CC models had been constructed. In these designs

a hollow box beam was the main strength member. This beam, running the entire length of the span, was covered with an aluminum, wood or fiberglas outer shell of the desired CC contour. Internal airflow was introduced into each end of the foil and flowed through the inside of the box beam. It would then exit the beam at right angles to the inlet flow path by passing through a series of holes or slots drilled into its aft vertical leg. The air then flowed to and through the exit slot at the trailing edge of the airfoil.

This idea was abandoned for several reasons. The first was that holes in the box beam, required to redirect air toward the exit slot at the trailing edge of the airfoil, would weaken the beam. This factor may not have been of great consideration in the smaller models which had lighter airfoil loadings and lower internal air ducting requirements. It was important in this larger model. Having a span approximately three times longer than prior CC models and a planform area nearly four times greater, this model would have to sustain high airfoil loads over a long span. Internal ducting for an unrestricted flow within the airfoil would require so many cutouts along the span of the box beam that they would tend to weaken this important highly loaded structural member.

In addition, a smoother transition for the 90 degree direction change in internal air flow was desired. A series of holes or slots cause a rather sudden, and possibly turbulent change of flow direction.

Finally, the large amount of welding required in a 10 foot (3.1 m) long box beam, as well as other joining problems, would potentially lead to highly stressed conditions in the airfoil when under load. All the above factors made the box beam method of construction unacceptable. Hence, other design concepts were sought.

An airfoil designed to be constructed of aluminum, except for a detachable upper trailing edge section (referred to as the knife-edge), made of steel, was considered worthy of investigation. Envisioned was a design in which the main body of the airfoil was made in two contoured halves consisting of an upper and lower half bolted together, (see Figure 1), hollowed out to form the internal air duct, and structurally designed to be, in itself, the main load carrying member. The advantage foreseen in this type of structure was that a "cleaner" design would evolve, one which would avoid the problems mentioned in the preceding paragraph. Also, some weight reduction would be achieved - a less important but still significant factor.

The use of steel for the knife-edge was initially favored, primarily to minimize deflection of this member at the exit slot, and also because machining aluminum to the sharp trailing edge required might be difficult. The use of steel was abandoned when computations indicated that with a 100 degree F (37.8$^{o}$C) temperature rise in the tunnel, high thermal stresses and foil warpage at the joint between the knife-edge and the upper sections of the aluminum airfoil would occur. Computations showed

that an acceptable exit slot deflection could be realized using aluminum. It was therefore decided to make the knife edge of aluminum and thus eliminate the thermal stress problem.

The idea of an all-aluminum airfoil was then pursued and, after a study of preliminary design alternatives a preferred concept was selected (Figure 2). Guided by a detailed investigation of all critical stress areas, formal design was begun. A summary of the calculated stresses in major elements of the design is given in Table 1.

## FINAL DESIGN

The major design problems encountered during the development of the final design were mainly structural in nature. Within the dimensional constraints of the outer contour, a large percentage of the cross section area had to be used for ducting the internal air flow. The requirement for a large internal duct structurally reduces the moment of inertia of the cross section. It was computed that as a beam either simply supported or fixed on each end, the deflection at the mid-span was unacceptable. It was also shown that the stresses would exceed the permitted stress limit. Further design study of this problem and subsequent stress analysis, indicated that an all-aluminum design using high strength aluminum, type 7075-T6, meeting all requirements was structurally possible, provided the foil was supported by two struts located 5 feet (1.52 m) apart centrally from mid-span, and that the ends of the airfoil were supported but free to accommodate bending i. e., pivoted and free to slide on their supports (Figures 1 & 3).

The ends were supported by a unique pivoted slide (Figure 4). The ends of the airfoil, made as a hollow rectangle in cross section, were vertically restrained but free to slide spanwise in a support bracket which was free to rotate about an axis parallel to the tunnel axis. In this manner the end supports were, in beam theory terminology, "simply supported" as required.

The struts (Figure 5) were designed to carry the maximum compressive load of 4400 lbf (19.6KN) each without buckling. These struts were designed not only to support the load, but to also minimize their disturbance of airflow in the tunnel, especially in the vicinity of the airfoil model. The struts were designed to be joined to the model with "Monoball" spherical bearings to accommodate foil bending and to allow for changes in pitch angle. It was important that the centerlines of the "Monoball" bearings coincide with the centerlines of the support bearings located in the tunnel wall to avoid binding when changing pitch angle of the foil. After this alignment was made, the struts, which passed through the slots in the tunnel floor, were shimmed and rigidly bolted to a lower metal plate (Figures 3 & 6). This plate was set in position by adjusting screws, then shimmed and bolted to the underside of the tunnel floor structure. Other shims and adjusting screws were also provided

at the lower end of each strut for precise vertical alignment of the struts so that no eccentric loading could occur which might cause a buckling failure of a strut.

To provide a smooth unrestricted flow path for internal airflow with minimal structural degradation, the inside of the two halves of the airfoil were machined out to allow the internal air to enter the airfoil and, with a gradual curve, flow into the rear cavity (see Figure 7). In this way not only a smooth flow path was achieved, but it also allowed most of the airfoil forward of the 50 percent chord to be of solid metal. This greatly strengthened the airfoil.

The airfoil structure had to be capable not only of withstanding the high external aerodynamic loads but also the internal pressure which, because of the large internal passage area exposed to this pressure, constituted a total internal loading of 31,700 lbf (141KN). Since design requirements for internal ducting and the installation of pressure tubes, etc. dictated that the airfoil be made in two sections for manufacturing purposes, this internal pressure tended to exert a considerable separating force within this two part structure.

At first it was intended to join the two halves of the airfoil using bolts only on the solid forward section. Analysis showed, however, that internal pressurization would impose too high a load on the hold down/ adjusting screws needed for adjusting the knife-edge slot gap. To overcome this problem, 14 of the screws which join the knife-edge to the upper half of the airfoil were made long enough to screw into the lower foil and thus join the two halves together at this location also (Figure 8). These bolts were made to pass through tubular spacers so as not to distort the airfoil configuration when tightened.

The bolts joining the two halves of the airfoil in the forward section serve two purposes, the first, and most obvious, is to secure the two halves together. The second, and not so obvious, is to sustain the large horizontal shear force of 103,000 lbf (458KN) which acts along the interface of the two halves when the beam is under maximum aerodynamic loading. For this reason high shear strength shoulder bolts were used with additional dowels required to withstand this shear force.

To provide for the airflow passage, each end of the airfoil (made rectangular in shape for mounting purposes in the manner previously described) was also made hollow by cutting away a rectangular duct area of the required 11 $in^2$ (71 $cm^2$) (Figure 2). Provision was made to attach a sealed transition chamber from the rectangular opening to a 5 inch (12.7 cm) diameter flexible hose connected to the external air supply (Figure 9). In this way the airfoil was free to rotate when changing the pitch angle and free to move spanwise under load without impeding air flow into the airfoil. Although a large portion of the airfoil ends were cut away for the air passage and the external rectangular dimensions were constrained to fit within the outer contour of the airfoil, the ends

could still be designed to structurally withstand the load imposed on them. This was made possible to a great extent by the pivoted mounting arrangement which prevented ends of the foil from being subjected to bending stresses.

To measure the pressure distribution on the surface of the airfoil, a total of 108 holes, each 0.040 inches (1.02 mm) in diameter were bored with their centerlines normal to the surface of the airfoil. Inside the foil, 0.065 inch (1.65 mm) O. D. x 0.047 inch (1.19 mm) I. D. stainless steel tubing led from each hole through ducts machined in the inner surface of the airfoils (Figures 10 & 12)to opposite ends for attachment into external instrumentation which measured the pressure.

An angle of attack indicator (Figure 11) was installed inside the airfoil with conductor wires leading to external readout instrumentation.

## MANUFACTURE

Very few problems were encountered throughout the entire machining process, considering the size, the relative thinness of the airfoil compared to its span, and the general complexity of machining a airfoil shape comprised of four separate sections which had to meet very close dimensional tolerances when assembled. The 7075-T6 aluminum exhibited excellent machining properties; even the sharp trailing edge of the knife-edge piece machined beautifully. However, one problem did arise in rough-machining one half of the airfoil on the ONSRUD profile mill. This machine is a numerically (tape) controlled machine which utilizes two adjustable-angle rotary heads driving ball mill cutters and is capable of machining a three dimensional profile. The mill makes its machining cut as it passes spanwise along the airfoil producing a scalloped surface. The size and depth of these scalloped cuts can be reduced by decreasing the depth of cut per pass and by increasing the number of passes, both of which are programmed into the machine. Time being an important factor, our program leaned toward minimizing machining time. The surface finish achieved was not the best. Also, the multiple cutting edges of the ball mill generate more heat than does a single cutting edge tool as used on a planer. This heat generation increases the chance of warpage in a thin part, especially when considerable material is to be removed. For this reason rough machining of only the one section of the airfoil was performed on the ONSRUD. The remaining three sections were both rough and finish machined on the Rockford planer, which produced excellent results both in dimensional control as well as surface finish.

Because of the length and thin cross section of the airfoil parts, considerable care had to be taken to minimize distortion or warpage during the machining process. By taking light cuts and by turning the airfoil section over several times, metal was removed from both sides until the final dimensions were achieved. This same precaution had to be taken in machining the struts made of HY-80 steel.

To prevent the loss of internal air from the airfoil, all joints and other potential sources of leakage as around bolt heads, and through threaded sections etc., had to be sealed. Sylgard No. 184, a silicone resin manufactured by Dow Corning, was used to seal the flat surfaced joint between the upper and lower halves of the airfoil and the juncture of the knife-edge where it is bolted to the upper half of the airfoil. An adhesive sealant, RTV No. 109, manufactured by General Electric, was used to seal the 0.065 inch (1.65 mm) O. D. pressure tap tubes at their exit from the airfoil. Epoxy Patch Type 3X made by Hysol Division of the Dexter Corporation was used to hold these tubes in internal tube ducts inside the airfoil. Teflon tape was used to seal under the heads of socket head and flat head set screws. Locktite Screw Lock, a Locktite Corporation product that permits the screw to be turned without loss of the product's locking properties, was also found to be an effective sealant around screw threads at pressures up to 30 psig (206.8 KPa). Dental plaster was used to fill in over any discontinuity in the outer surface such as around counterbores or threaded holes which penetrated the outer contour of the airfoil.

The leakage source which caused the most trouble was that of the pressure tap tube "bundles" as they exit through trough-shaped openings at both ends of the airfoil. Sealing the cavities between adjacent tubes bundled together was not as effective as desired. After many applications, however, an acceptable level of sealing was finally obtained. It is suggested that, for future designs, a better means be found for sealing pressure tap tubes. It is possible that a rubber packing gland with individual undersized holes for each tube might solve this problem. It should be added that the Epoxy Patch - Type 3X was found to be quite satisfactory in filling in any mismatch in adjoining surfaces; it hardens and adheres very well and can be readily handworked to create a smooth surfacc.

## CONCLUSIONS

To date tunnel tests indicate that the model has met all design requirements. Therefore, from the standpoint of design and manufacture, it is within the state of the art to produce a structurally viable, large scale aluminum model of a CC airfoil.


## ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Mr. Joseph B. Wilkerson, project engineer for the Aviation and Surface Effects Department, for his encouragement and guidance during the entire course of the project and Messrs. Luther Burgee and Anthony Rok for their many contributions to the solution of design problems.

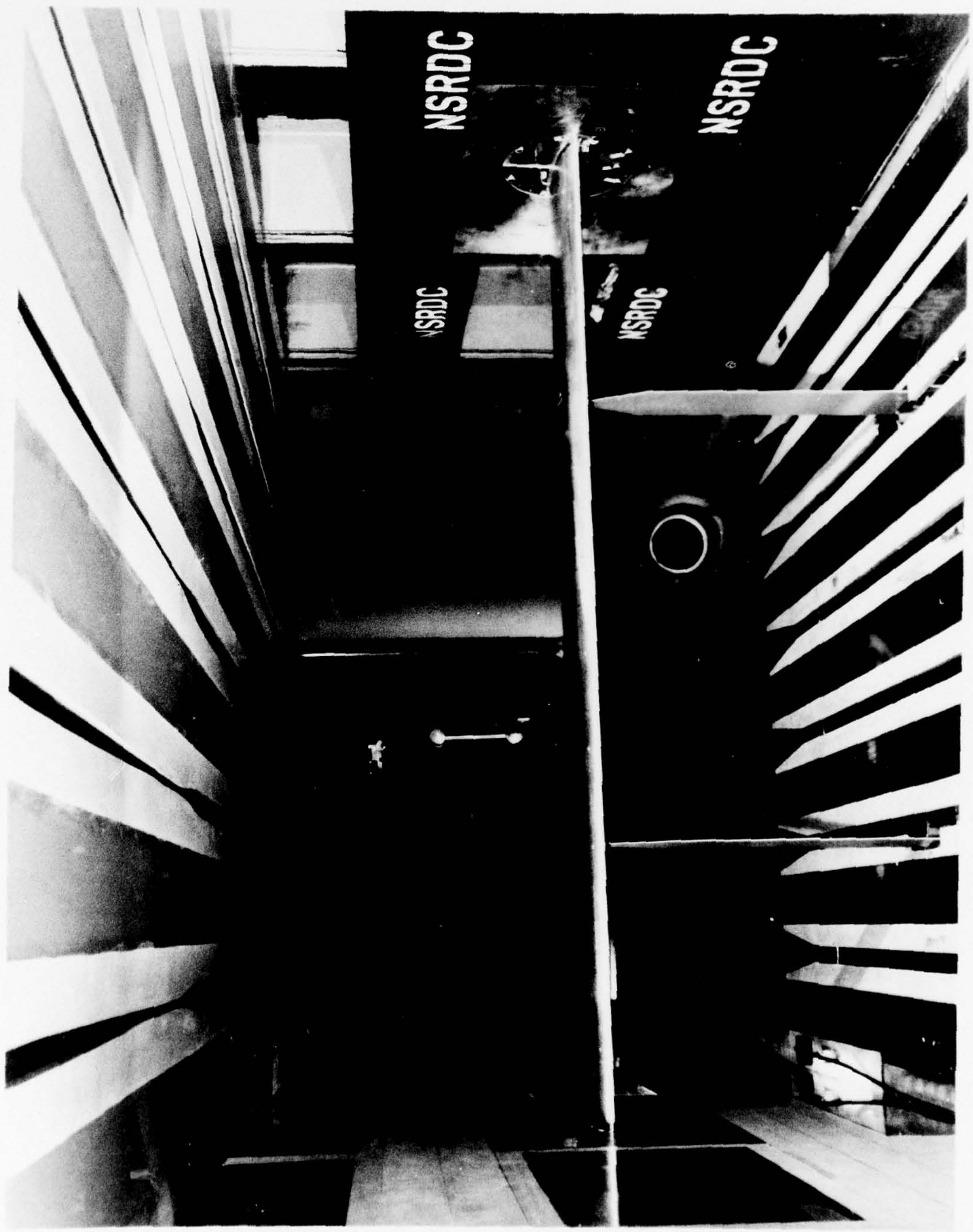
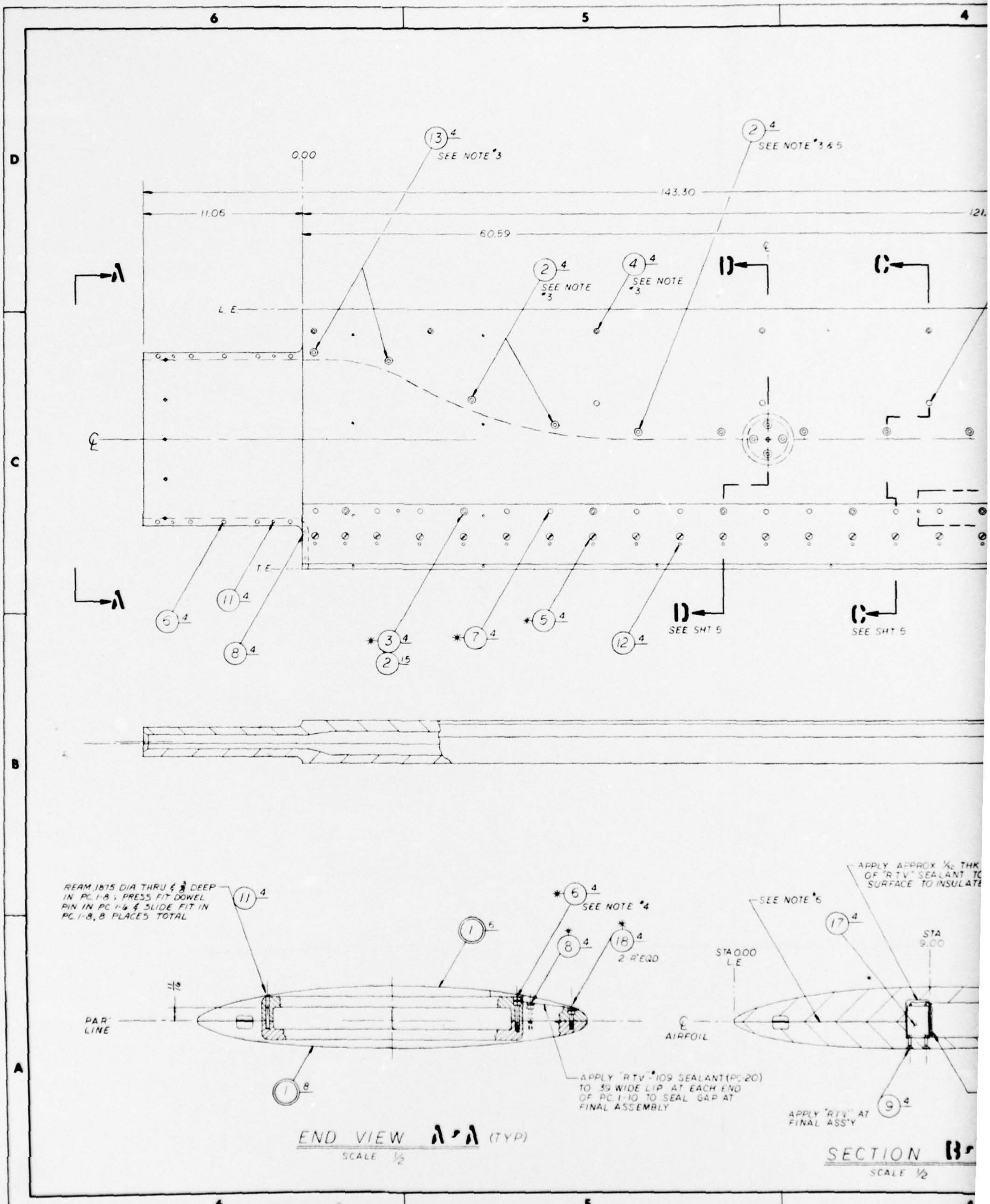



Figure 1  The Airfoil Model Installed in the Tunnel

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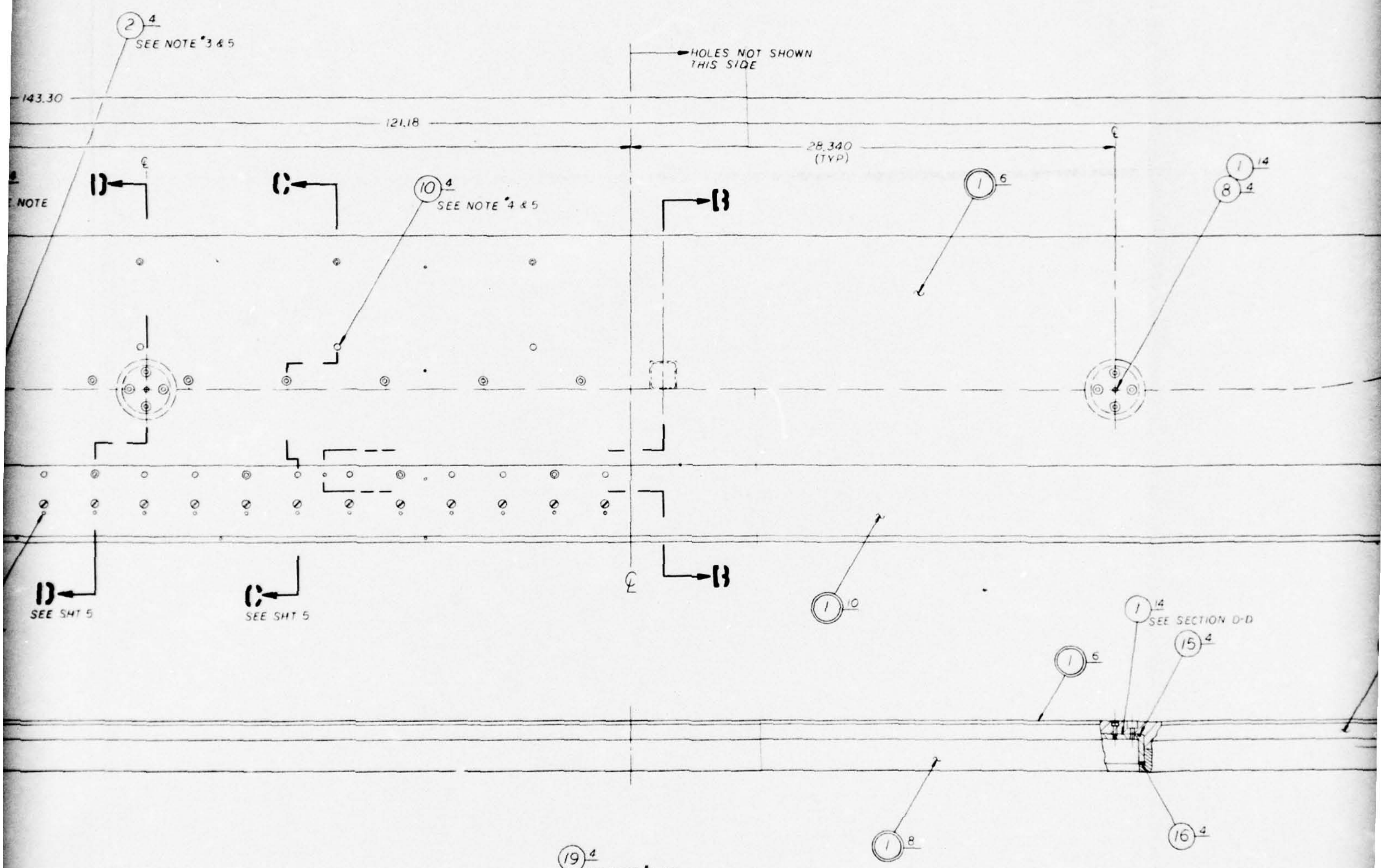
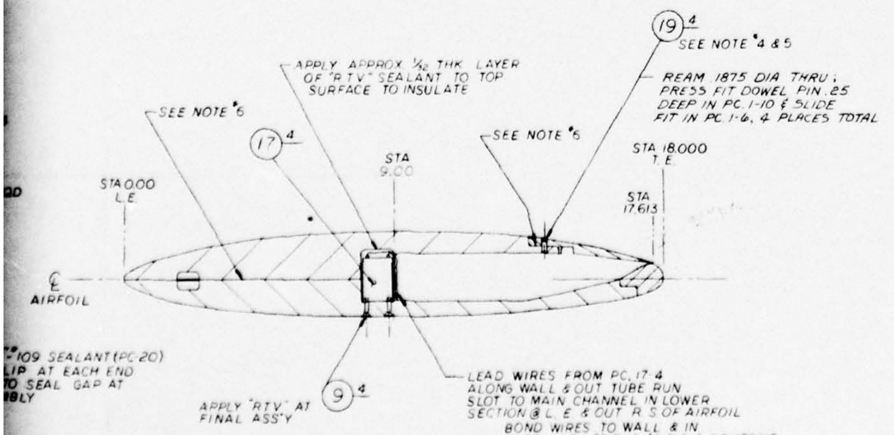
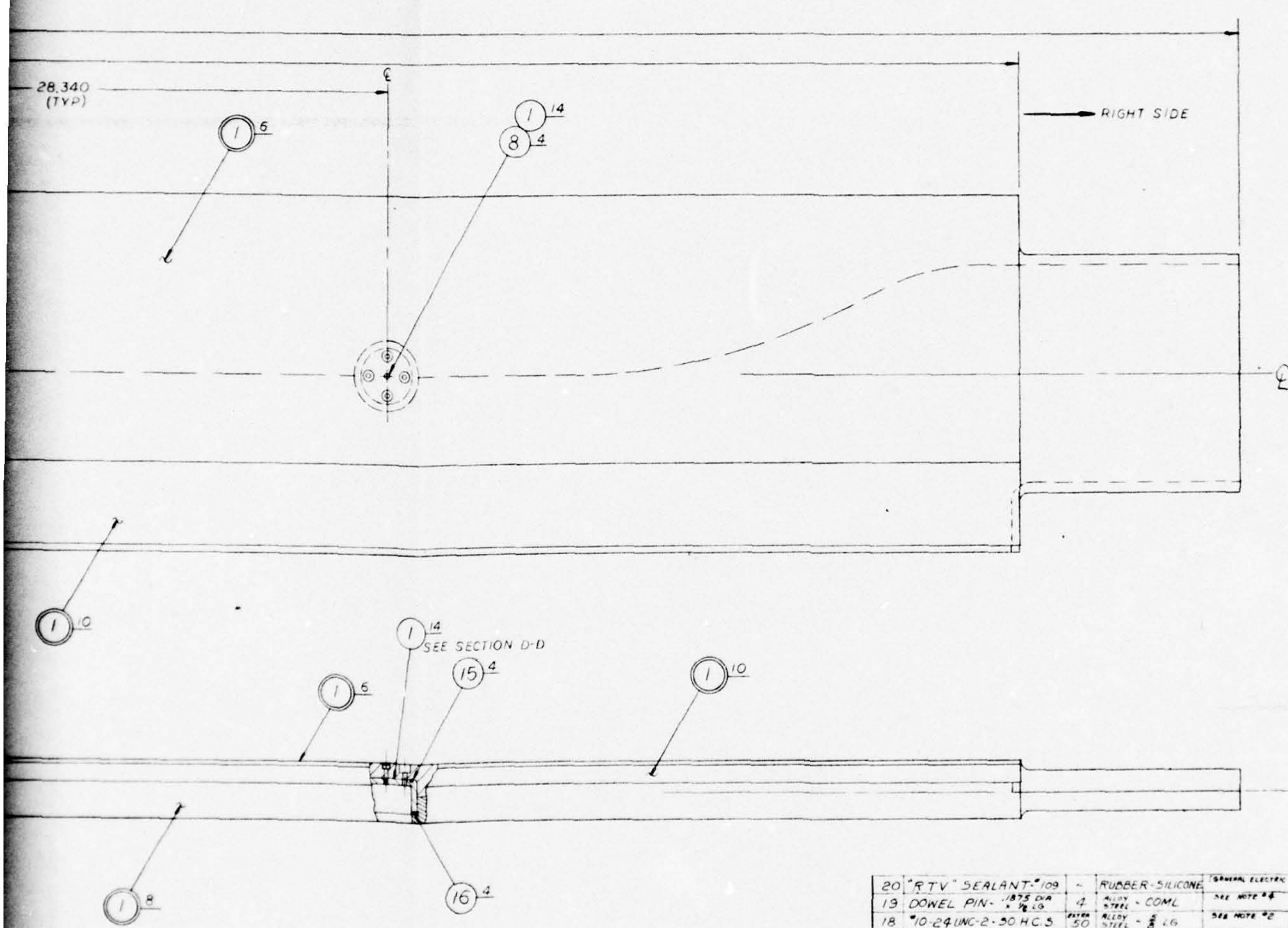



SECTION B-B
SCALE 1/2

NOTES:

1. REFER TO SHT 7 (UPPER), SHT 9 (LOWER) & SHT 10 (KNIFE EDGE) FOR PRESSURE TAP LOCATIONS (108 TOTAL)
2. ALL SCREWS DENOTED WITH * TO HAVE AN ULTIMATE TENSILE STRENGTH OF 170,000 psi MIN.
3. SHOULDER SCREWS TO HAVE AN ULTIMATE TENSILE STRENGTH OF 140,000 psi MIN.
4. SINGLE SHEAR STRENGTH OF DOWEL PINS TO BE:
   .375 DIA : 16,550 lbs MIN
   .1875 DIA : 4,150 lbs MIN
5. APPLY WAD OF COTTON OR SIMILAR MAT'L INTO DOWEL PIN HOLE OR SCREW HEX SOCKET AND APPLY A LAYER OF "DENTAL PLASTER" TO FILL HOLE & SAND FLUSH TO CONTOUR. (FOR HOLES ON AIRFOIL CONTOUR ONLY). LEAVE 2 ROWS OF JACK SCREWS (PC 5-4 & 12-4) TO BE FILLED AT TUNNEL ASS'Y.
6. MATING SURFACES TO BE THOROUGHLY CLEANED AND DRYED TO REMOVE SURFACE CONTAMINANTS. MIX SILICONE RESIN, PC-14, AND APPLY IN A VERY THIN COAT TO ONE SURFACE TO BE JOINED. THE SILICONE RESIN HAS A POT LIFE OF 2 HOURS AT 77° F (AT FINAL ASSEMBLY)
   WHEN SEPARATING THE SEALED SURFACES, AN INITIAL OPENING BREAK BETWEEN SURFACES MUST BE ESTABLISHED AFTER WHICH COMPLETE SEPARATION SHOULD READILY PROCEED.

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(1) E-3375-4
SCALE 1/3

FIGURE 2

| PC NO | NAME OF PIECE | NO. REQ'D | MATERIAL | STD. NAVY STOCK NO. | SOURCE |
|---|---|---|---|---|---|
| 20 | "RTV" SEALANT-#109 | ~ | RUBBER-SILICONE | (GENERAL ELECTRIC CO.) | CODE 297 |
| 19 | DOWEL PIN-.1875 DIA × ½ LG | 4 | ALLOY STEEL - COML | SEE NOTE #4 | ON ORDER |
| 18 | ✱10-24 UNC-2-SO.H.C.S | EXTRA 50 | ALLOY STEEL - ⅝ LG | SEE NOTE #2 | " |
| 17 | ANGLE-METER | 1 | STEEL-COML | | CODE 294 |
| 16 | O-RING SEAL-#2-151 | 2 | RUBBER-NITRILE (BUNA-N) | (PARKER SEAL CO.) | CODE 299 |
| 15 | " " -#2-148 | 2 | " " | " " " | CODE 299 |
| 14 | SEALANT-"SYLGARD" #184 | 1 GAL APPROX | SILICONE RESIN | (DOW CORNING CORP) | ON ORDER |
| 13 | SOCKET HEAD SHOULDER SCREW - .375 DIA × 1" LG | 4 | ALLOY STEEL | | " |
| 12 | ✱10-32 UNF-3-SLOTTED HD FLAT PT SET SC | 42 | -1⅛ LG | | " |
| 11 | DOWEL PIN-.1875 DIA × 1 LG | 8 | - COML | SEE NOTE #4 | " |
| 10 | " " -.375 DIA × 1¾ LG | 8 | - " | SEE NOTE #4 | " |
| 9 | ✱6-32 UNC-2-F.H.M.S | 4 | - ⅜ LG | | " |
| 8 | ✱10-24 UNC-2-SO.H.C.S | 4 | - ⅜ LG | SEE NOTE #2 | " |
| 7 | ✱10-32 UNF-3-F.H.SO.S | 28 | - ½ LG | SEE NOTE #2 | " |
| 6 | ✱10-24 UNC-2-SO.H.C.S | 20 | - 1 LG | SEE NOTE #2 | " |
| 5 | ¼-28 UNF-3-F.H.M.S | 42 | - 1⅛ LG | SEE NOTE #2 | " |
| 4 | SOCKET HEAD SHOULDER SCREW - .250 DIA × ¾ LG | 12 | | SEE NOTE #3 | " |
| 3 | ¼-20 UNC-2-F.H.SO.S | 14 | - 2⅛ LG | SEE NOTE #2 | " |
| 2 | SOCKET HEAD SHOULDER SCREW - .375 DIA × 1¼ LG | 18 | ALLOY STEEL | SEE NOTE #3 | " |
| 1 | ASSEMBLY | 1 | | | |

LIST OF MATERIAL—QUANTITIES FOR ONE

TOLERANCES UNLESS OTHERWISE SPECIFIED
ON MACHINE SURFACES
2 DECIMAL PLACES ±0.01 INCH
3 DECIMAL PLACES ±0.005 INCH
WHOLE NUMBERS OR FRACTIONS ±1/64 INCH
ANGLES ±15 MINUTES
ON OTHER SURFACES
SAW CUT ±1/16 INCH
MACHINE FLAME CUT ±1/16 INCH
FINISHES ARE RMS VALUES EXPRESSED IN MICRO INCHES

REFERENCES

DATE 4/23/76
DRAWN ROK
CHECKED
REVIEWED
APPROVED
DATE 5/7/76

7' X 10' T.W.T.
C.C. TRANS-AIRFOIL MODEL ASSEMBLY

SCALE NOTED

DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH & DEVELOPMENT CENTER
WASHINGTON, D.C. 20007

NSRDC NUMBER E—3375-4 REVISION C

E—3375-4

SHOPWORK REQUEST
172698K 5-11-76

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1-1619-200-26

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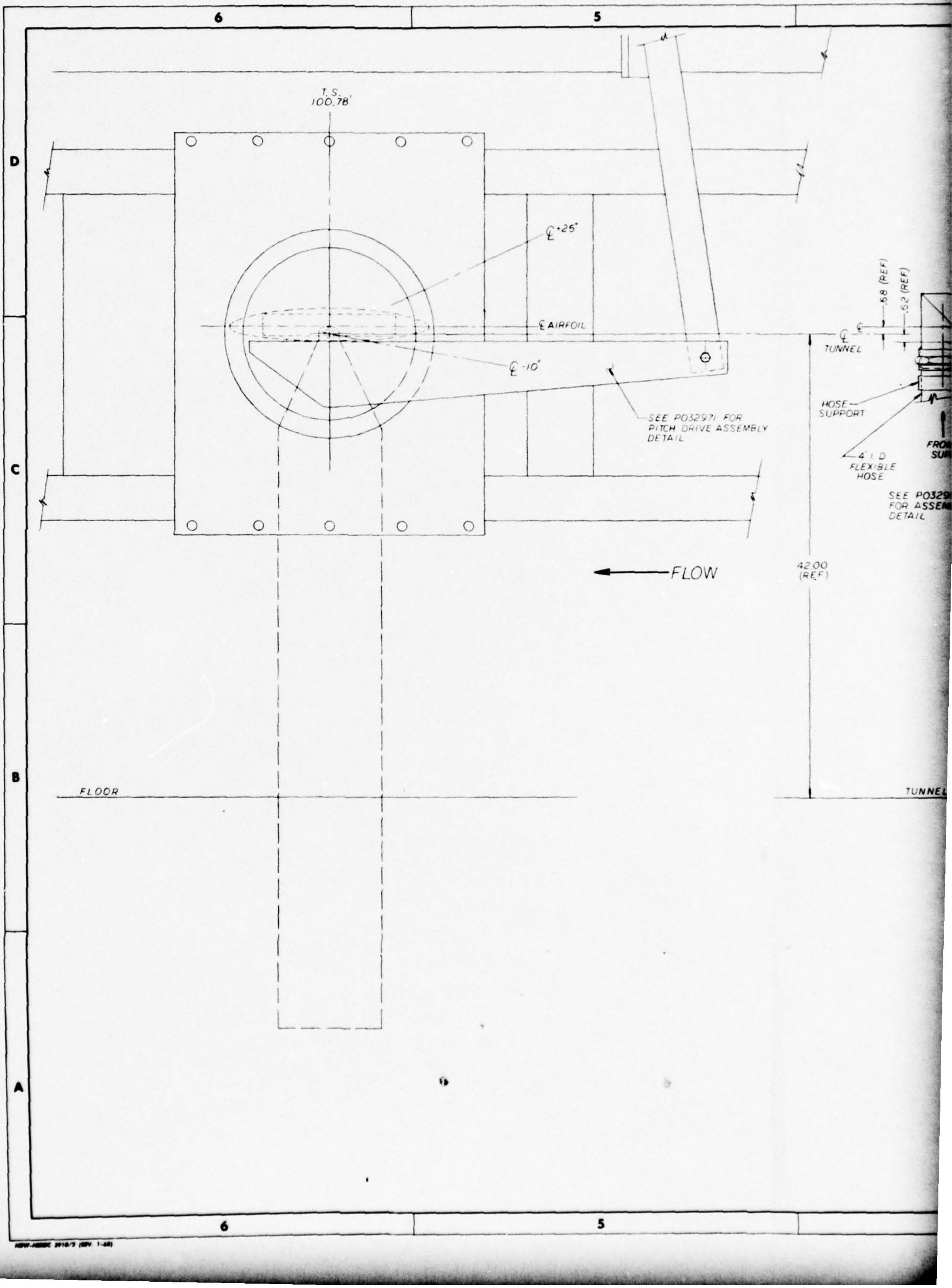

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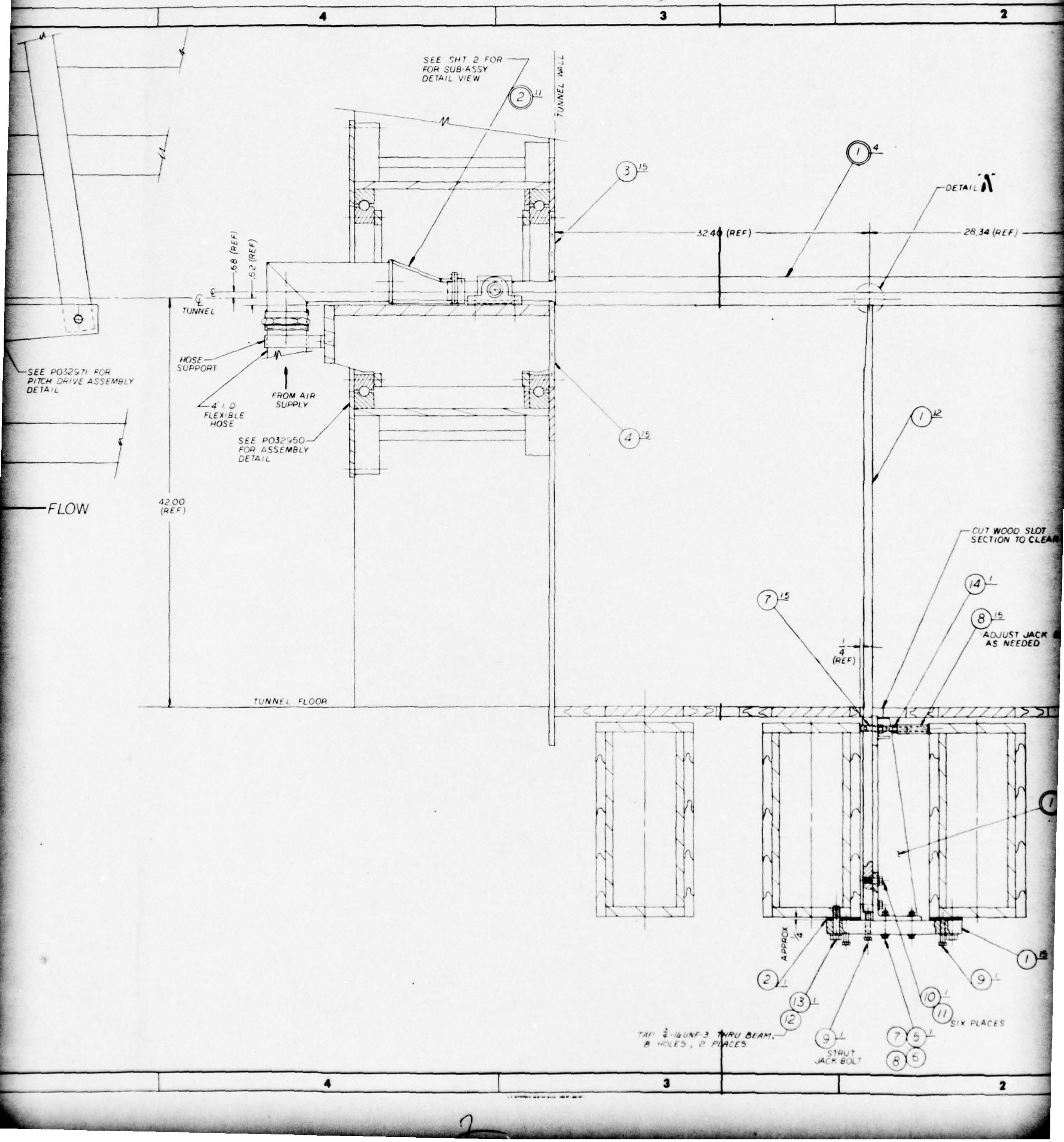
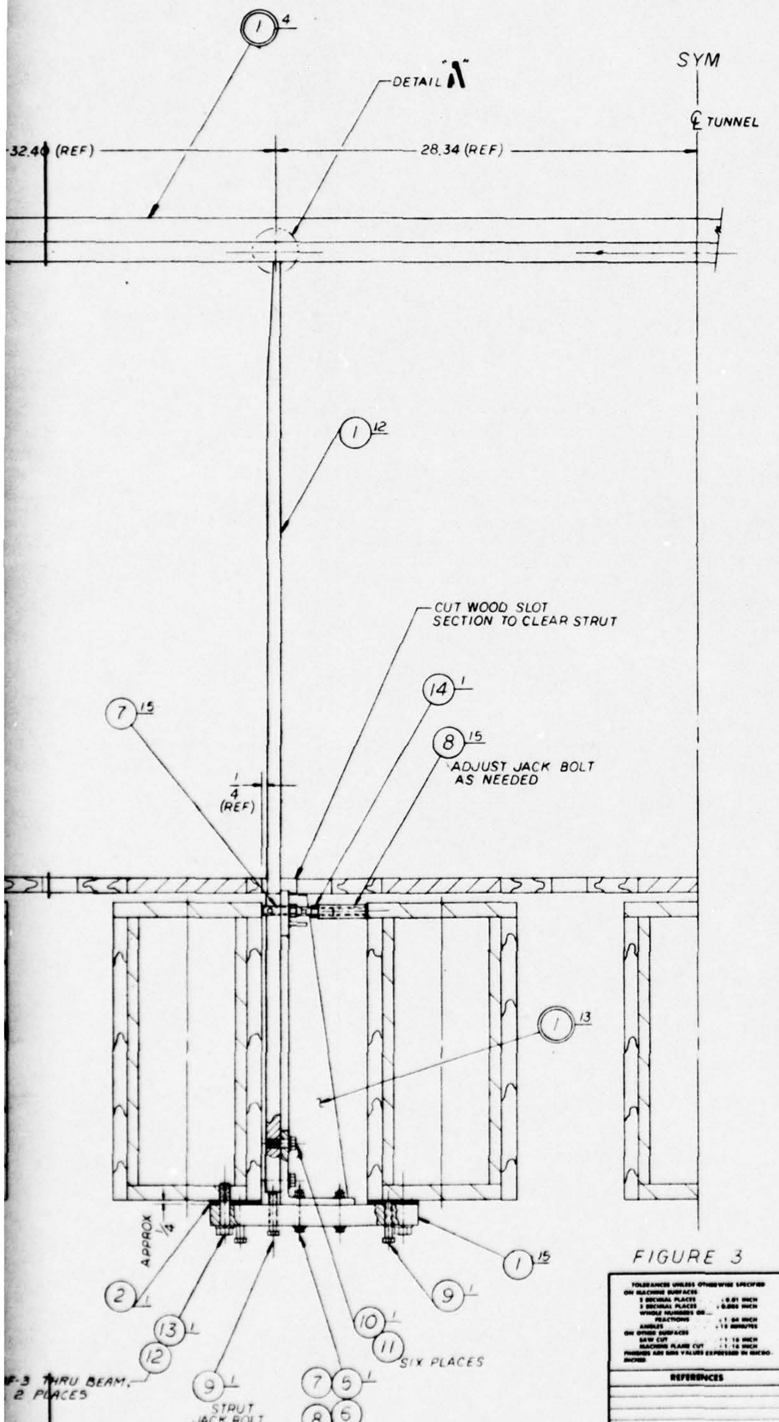
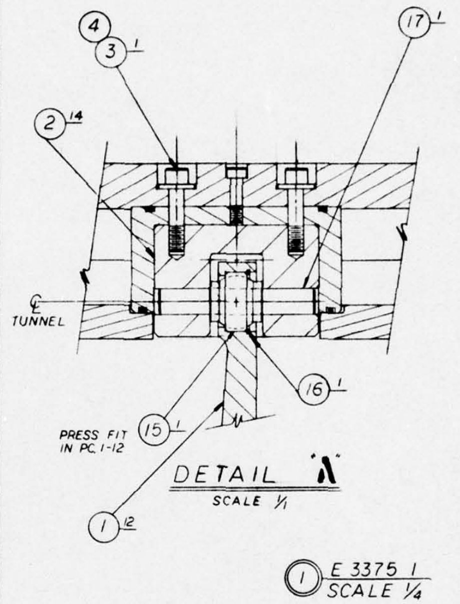
+25°
AIRFOIL
-10°
TUNNEL
.58 (REF)
.52 (REF)
SEE PO32971 FOR PITCH DRIVE ASSEMBLY DETAIL
HOSE SUPPORT
4" I.D. FLEXIBLE HOSE
FLOW
42.00 (REF)
FLOOR
TUNNEL



4
3
2
SEE SHT 2 FOR
FOR SUB-ASSY
DETAIL VIEW
TUNNEL WALL
DETAIL "A"
32.40 (REF)
28.34 (REF)
.68 (REF)
.52 (REF)
TUNNEL
HOSE SUPPORT
SEE P032971 FOR
PITCH DRIVE ASSEMBLY
DETAIL
FROM AIR
SUPPLY
4" I.D.
FLEXIBLE
HOSE
SEE P032950
FOR ASSEMBLY
DETAIL
FLOW
42.00
(REF)
TUNNEL FLOOR
CUT WOOD SLOT
SECTION TO CLEAR
ADJUST JACK
AS NEEDED
1/4
(REF)
APPROX 1/4
SIX PLACES
TAP 3/4-16UNF-3 THRU BEAM,
8 HOLES, 2 PLACES
STRUT
JACK BOLT
4
3
2




E 3375 1
SCALE 1/4

FIGURE 3

| PC. NO. | NAME OF PIECE | NO. REQ'D | MATERIAL | STD. NAVY STOCK NO. | SOURCE |
|---|---|---|---|---|---|
| 17 | DOWEL PIN - 7/16 DIA x 2 5/8 LG | 2 | ALLOY STEEL ~ | SINGLE SHEAR STRENGTH = 22,550 lb min | CODE 294 |
| 16 | RETAINING RING | 2 | STEEL ~ #5008-100 | "TRUARC" WALDES KOHINOOR INC. | CODE 294 |
| 15 | "MONOBALL" ~ SELF-ALIGNING BRG | 2 | ~ COML #BSSR-7295 | (SOUTHWEST PRODUCTS CO.) | CODE 294 |
| 14 | 5/8-11UNC-2-HEX NUT | 4 | | | |
| 13 | 3/4 LOCK WASHER | 16 | | | |
| 12 | 3/4-16UNF-3-HEX BOLT | 16 | ~ 5" LG | SAE - GRADE 5 | ON ORDER |
| 11 | 1/2 LOCK WASHER | 12 | | | |
| 10 | 1/2-13UNC-2-HEX BOLT | 12 | ~ 1 1/2 LG | SAE - GRADE 5 | ON ORDER |
| 9 | " " " " | 12 | ~ 2 1/2 LG | | " |
| 8 | 3/8 LOCK WASHER | EXTRA 20 | | | |
| 7 | 3/8 PLAIN WASHER | 12 | | | |
| 6 | 3/8-16UNC-2-HEX NUT | 12 | | | |
| 5 | " " -HEX BOLT | 12 | ~ 2 1/2 LG | SAE - GRADE 5 | ON ORDER |
| 4 | 1/4 PLAIN WASHER | 8 | | | |
| 3 | 1/4-28UNF-3-SO.H.C.S. | 8 | ALLOY STEEL ~ 1 1/8 LG | ULTIMATE TENSILE STRENGTH = 170,000 PSI MIN | ON ORDER |
| 2 | CHOCKING RESIN W/ HARDENER | 2 qt | ~ #610FR | (PHILADELPHIA RESINS CO.) | |
| 1 | ASSEMBLY | 1 | | | |

LIST OF MATERIAL—QUANTITIES FOR ONE

TOLERANCES UNLESS OTHERWISE SPECIFIED
ON MACHINE SURFACES
2 DECIMAL PLACES ±0.01 INCH
3 DECIMAL PLACES ±0.005 INCH
WHOLE NUMBERS OR FRACTIONS ±1/64 INCH
ANGLES ±15 MINUTES
ON OTHER SURFACES
SAW CUT ±1/16 INCH
MACHINE FLAME CUT ±1/16 INCH
FINISHES ARE RMS VALUES EXPRESSED IN MICRO-INCHES

REFERENCES

DATE 5/4/76
DRAWN ROK
CHECKED
REVIEWED
APPROVED
DATE 5/13/76

7' X 10' TWT
CC TRANS-AIRFOIL MODEL
TUNNEL INSTALLATION
SCALE 1/4

DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH & DEVELOPMENT CENTER
WASHINGTON, D.C. 20007

NSRDC NUMBER E-3375-1
REVISION

REVISIONS

| REV. | ZONE | DESCRIPTION | BY | DATE | APP'D |
|---|---|---|---|---|---|

PRINT RECORD

| SENT TO | NO. | DATE |
|---|---|---|
| 294 | 3 | 13 |
| 4222 | 4 | May |
| 4141 | 2 | 1976 |

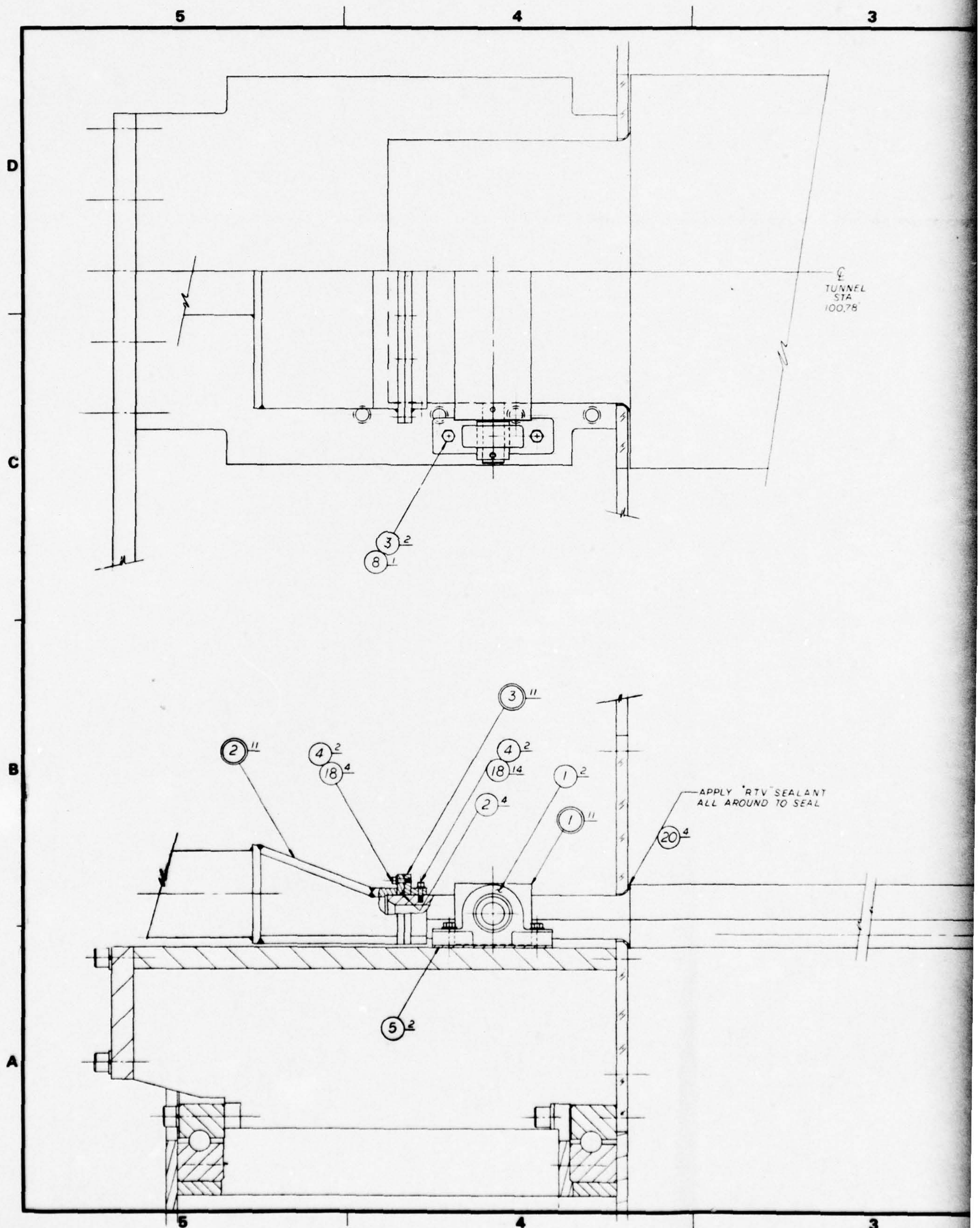
SHOPWORK REQUEST
172 698 L 5-13-76

PROJECT NUMBER
1-1619-200-26

REVIEWED BY

| CODE | NAME | DATE |
|---|---|---|

E-3375-1


5
4
3
D
C
B
A
TUNNEL
STA
100.78
3 2
8 1
2 11
4 2
18 4
3 11
4 2
18 14
2 4
1 2
1 11
APPLY "RTV" SEALANT
ALL AROUND TO SEAL
20 4
5 2

| SHOPWORK REQUEST NO. | | PRINT RECORD | | |
|---|---|---|---|---|
| | | SENT TO | NO. | DATE |
| 172698L | 5-13-76 | 4225 | 3 | 13 |
| | | 4222 | 3 | May |
| | | 4141 | 2 | 1976 |

| STRESS ENG'R | | | REVIEWED BY | | | PROJECT NUMBER |
|---|---|---|---|---|---|---|
| CODE | NAME | DATE | CODE | NAME | DATE | |

REVISIONS

| REV. | ZONE | DESCRIPTION | BY | APP'D | DATE |
|---|---|---|---|---|---|

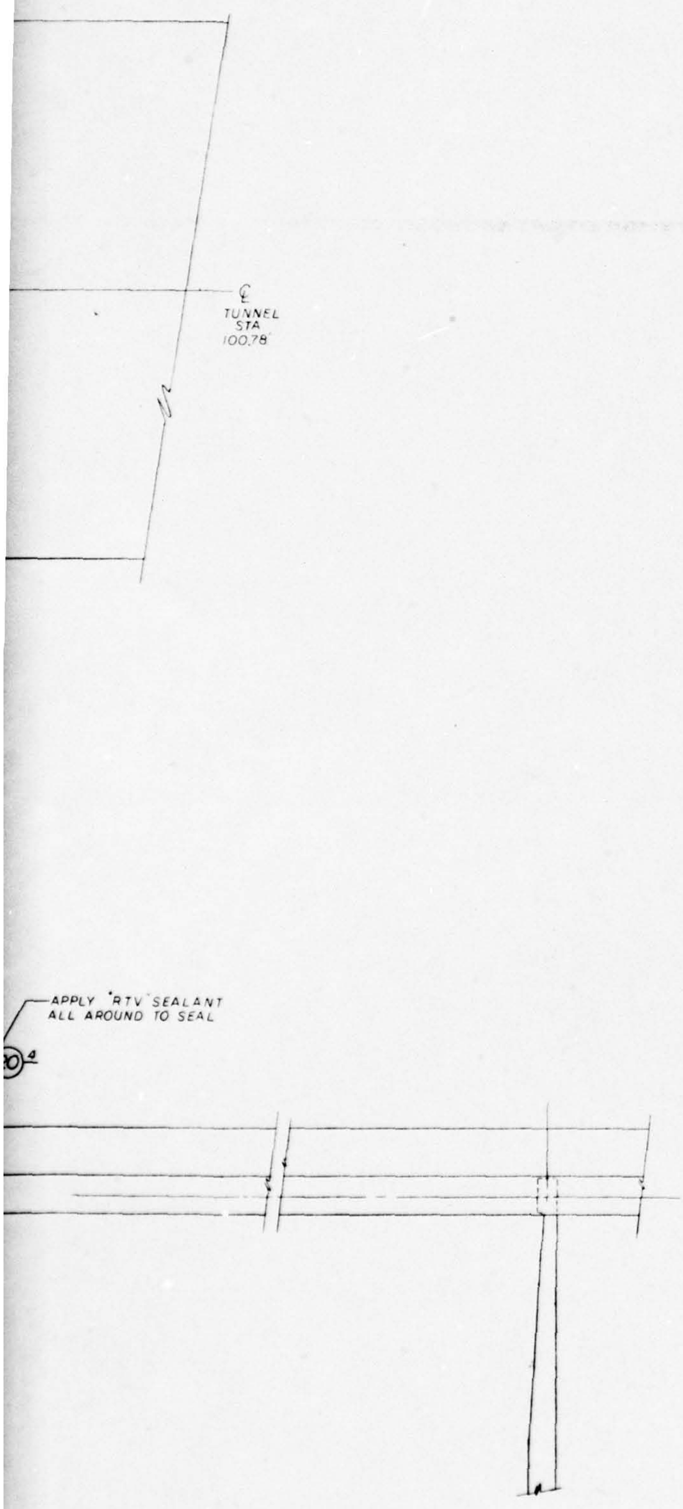



FIGURE 4

| PC NO. | NAME OF PIECE | NO REQ'D | MATERIAL | SOURCE |
|---|---|---|---|---|
| 5 | SHIM - 1½ x 1⅝ x ⅛ STK | 4 | STEEL | |
| 4 | #10 LOCK WASHER | EXTRA 50 | STEEL | |
| 3 | ⅜-16UNC-2-HEX BOLT | 8 | STEEL - 1⅜ LG | GRADE 5 CODE 294 |
| 2 | O-RING SEAL - #2-174 | 2 | RUBBER - NITRILE (BUNA-N) | (PARKER SEAL CO) CODE 294 |
| 1 | PILLOW BLOCK | 4 | STEEL - #06916-5H | (BOSTON GEAR) CODE 294 |

D

LIST OF MATERIAL - QUANTITIES FOR ONE

REFERENCES

DATE 5-2-76
DRAWN ROK
CHECKED
DESIGNED
REVIEWED
APPROVED
DATE 5/12/76

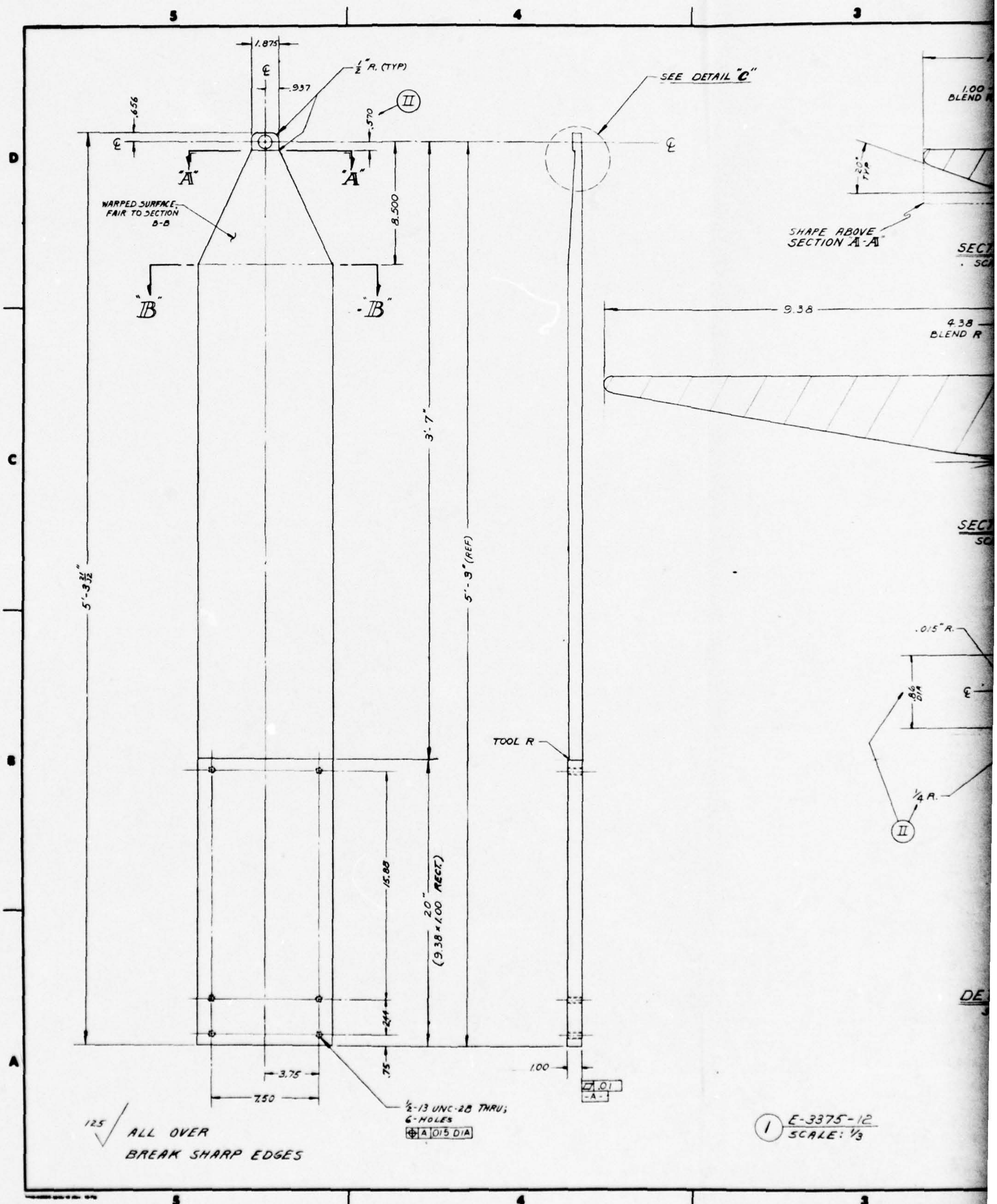
7' x 10' T.W.T.
C C TRANS-AIRFOIL MODEL
TUNNEL INSTALLATION SECTION DETAIL

SCALE: 1/2

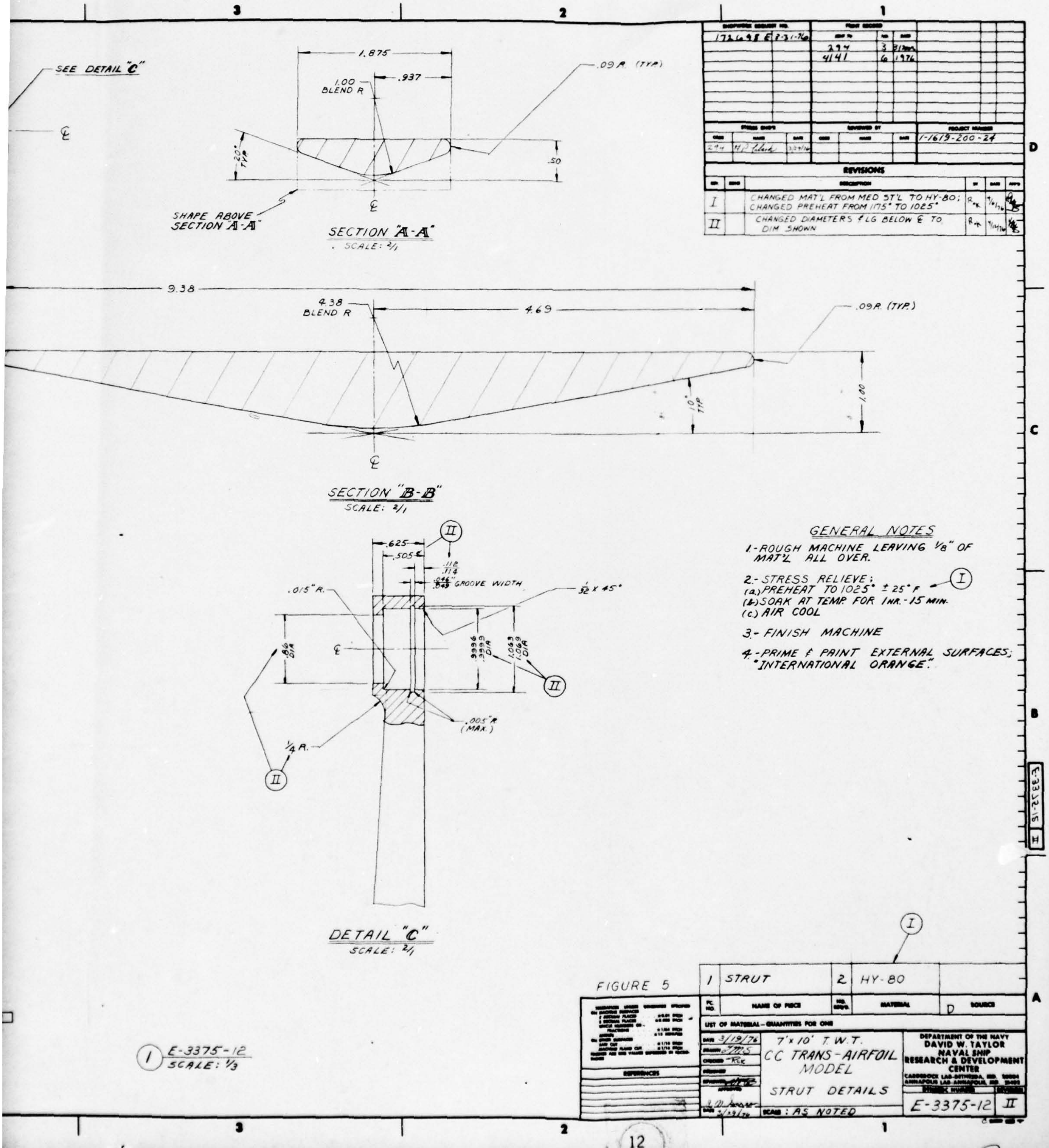
DEPARTMENT OF NAVY
DAVID W. TAYLOR NAVAL SHIP RESEARCH & DEVELOPMENT CENTER

DTNSRDC NUMBER: E-3375-2
REVISION

E-3375-2



1.875
.937
1/2" R. (TYP)
.656
.570
II
SEE DETAIL "C"
"A"
"A"
WARPED SURFACE FAIR TO SECTION B-B
8.500
"B"
"B"
3'-7"
5'-3 21/32"
5'-9" (REF)
15.88
20" (9.38 x 1.00 RECT.)
2.44
.75
3.75
7.50
TOOL R
1.00
.01
-A-
1/2-13 UNC-2B THRU; 6-HOLES
A .015 DIA
1.00
BLEND R
20° TYP
SHAPE ABOVE SECTION A-A
9.38
4.38
BLEND R
.015" R.
.86 DIA
1/4 R.
125 ALL OVER
BREAK SHARP EDGES
1 E-3375-12
SCALE: 1/3
5
4
3
D
C
B
A



SEE DETAIL "C"
1.875
.937
1.00 BLEND R
.09 R. (TYP)
20° TYP
.50
SHAPE ABOVE SECTION "A-A"
SECTION "A-A"
SCALE: 2/1
9.38
4.38 BLEND R
4.69
.09 R. (TYP.)
10° TYP
1.00
SECTION "B-B"
SCALE: 2/1
.625
.505
.118
.114
.046 .043 GROOVE WIDTH
.015" R.
1/32 x 45°
.86 DIA
.9996 .9999 DIA
1.063 1.069 DIA
.005" R (MAX.)
1/4 R.
DETAIL "C"
SCALE: 2/1
172698 E 2-21-76
294
4141
1-1619-200-24
REVISIONS
I CHANGED MAT'L FROM MED ST'L TO HY-80; CHANGED PREHEAT FROM 1175° TO 1025°
II CHANGED DIAMETERS & LG BELOW ℄ TO DIM SHOWN
GENERAL NOTES
1.-ROUGH MACHINE LEAVING 1/8" OF MAT'L ALL OVER.
2.-STRESS RELIEVE;
(a.) PREHEAT TO 1025° ± 25° F
(b.) SOAK AT TEMP. FOR 1 HR.-15 MIN.
(c) AIR COOL
3.- FINISH MACHINE
4.-PRIME & PAINT EXTERNAL SURFACES; "INTERNATIONAL ORANGE".
1 STRUT 2 HY-80
PC NO. NAME OF PIECE NO. REQ'D MATERIAL SOURCE
LIST OF MATERIAL - QUANTITIES FOR ONE
DATE 3/19/76
7'x 10' T.W.T.
CC TRANS-AIRFOIL MODEL
STRUT DETAILS
SCALE: AS NOTED
DEPARTMENT OF THE NAVY
DAVID W. TAYLOR NAVAL SHIP RESEARCH & DEVELOPMENT CENTER
E-3375-12 II
1 E-3375-12 SCALE: 1/3


FIGURE 5

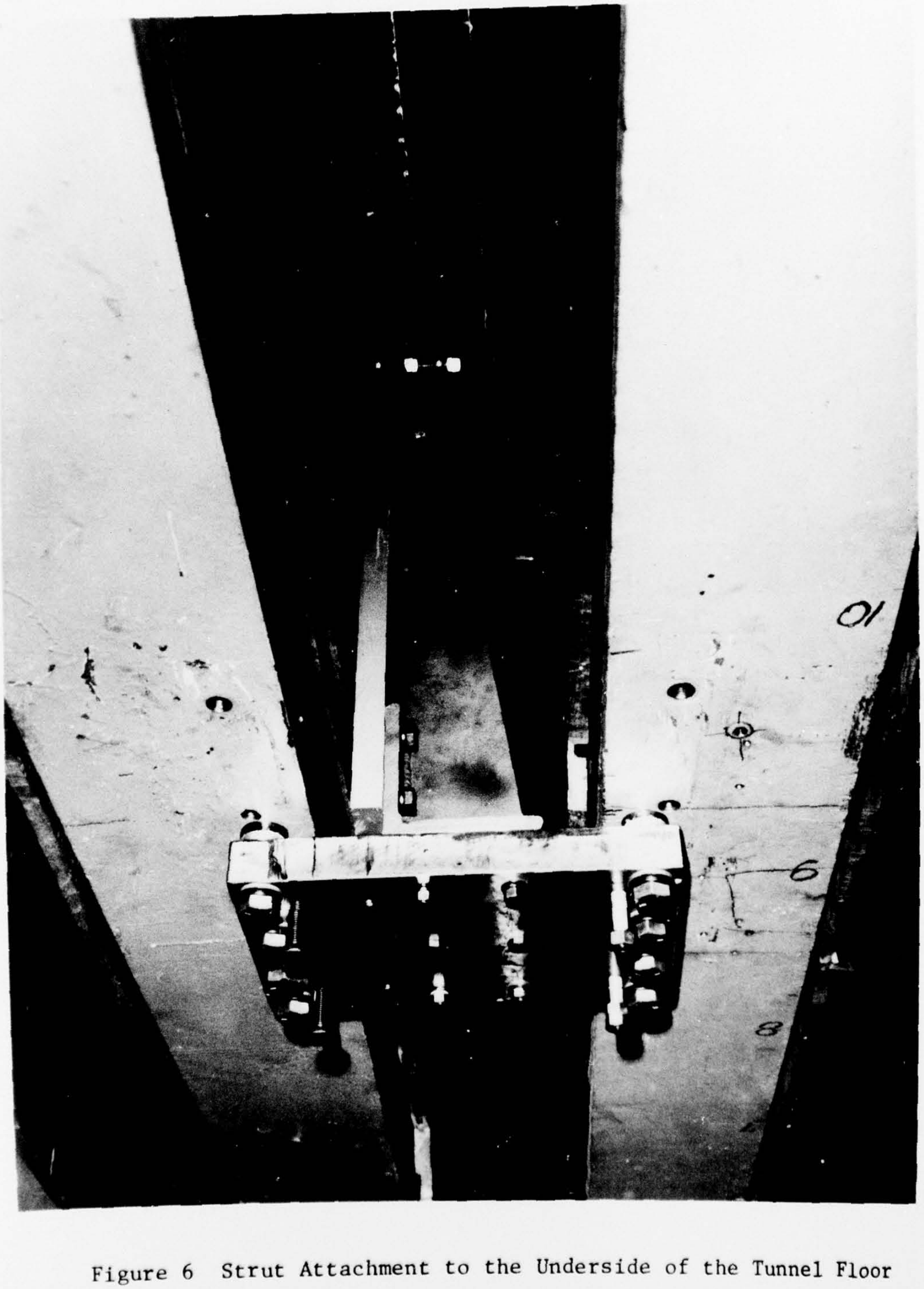
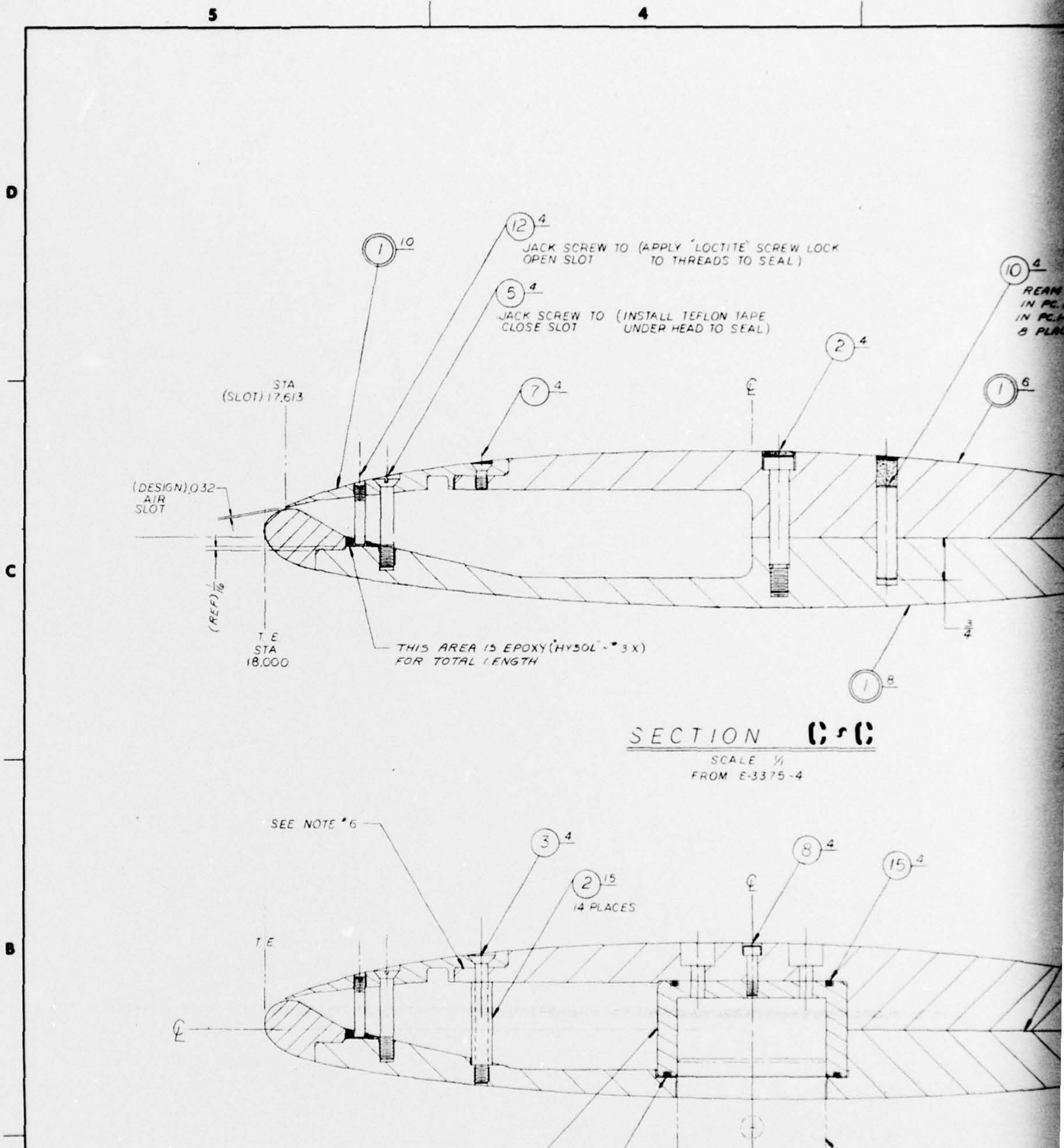


Figure 6  Strut Attachment to the Underside of the Tunnel Floor

Figure 7 Internal View of the Upper and Lower Halves of the Airfoil Model Showing Cutout for Internal Air Flow and Tubing Runs



5
4
D
C
B
A
JACK SCREW TO OPEN SLOT (APPLY "LOCTITE" SCREW LOCK TO THREADS TO SEAL)
JACK SCREW TO CLOSE SLOT (INSTALL TEFLON TAPE UNDER HEAD TO SEAL)
STA (SLOT) 17.613
(DESIGN) .032 AIR SLOT
(REF) 1/16
T.E STA 18.000
THIS AREA IS EPOXY ("HYSOL" - *3 X) FOR TOTAL LENGTH
SECTION C-C
SCALE 1/1
FROM E-3375-4
SEE NOTE *6
14 PLACES
T.E
STA 9.000
CHECK PC 1-14 FOR A
WITH PC 2-14 BEFORE
ASSEMBLY OF AIRFOIL
SECTION D-D
SCALE 1/1
FROM E-3375-4

| SHOPWORK REQUEST NO. | | PRINT RECORD | | |
|---|---|---|---|---|
| | | SENT TO | NO. | DATE |
| 172698 K | 5-11-76 | 294 | 3 | 11 |
| | | 4222 | 4 | [illegible] |
| | | 4141 | 2 | 1976 |

| STRESS ENG'R | | | REVIEWED BY | | | PROJECT NUMBER |
|---|---|---|---|---|---|---|
| CODE | NAME | DATE | CODE | NAME | DATE | |
| 294 | [illegible] | 5/5/76 | | | | 1-1619-200-26 |

**REVISIONS**

| REV | ZONE | DESCRIPTION | BY | DATE | APP'D |
|---|---|---|---|---|---|

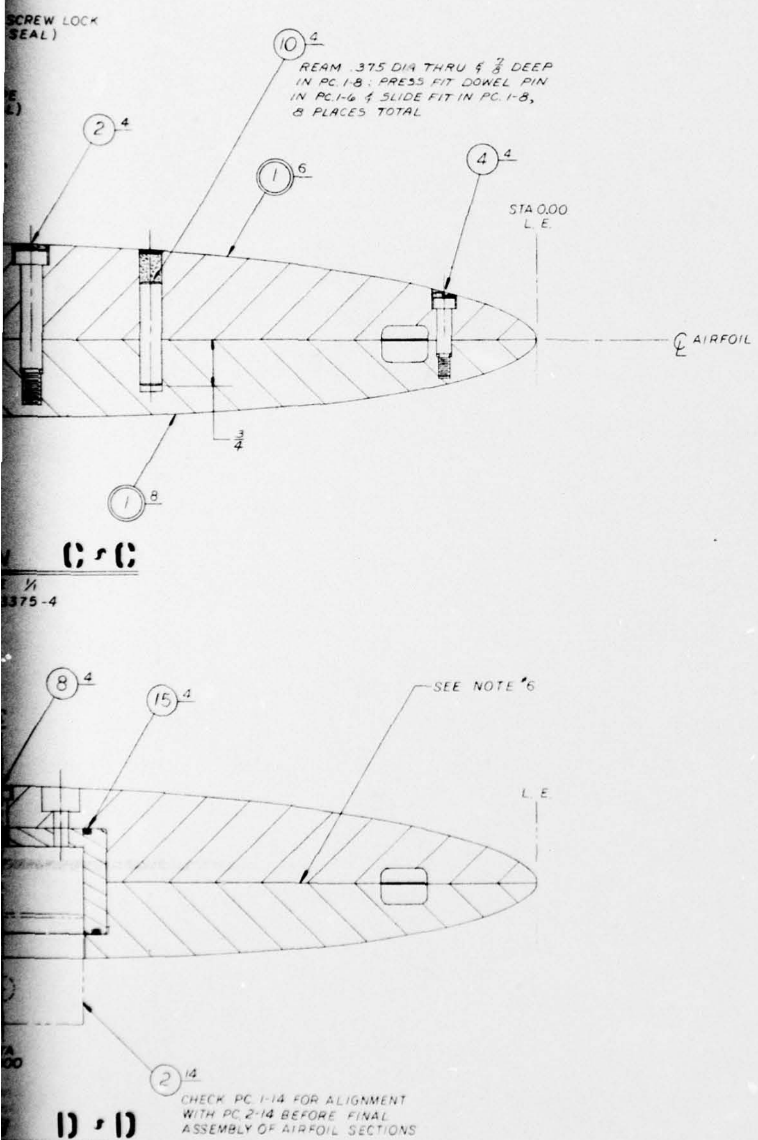



FIGURE 8

| PC NO. | NAME OF PIECE | NO. REQ'D | MATERIAL | D SOURCE |
|---|---|---|---|---|
| LIST OF MATERIAL - QUANTITIES FOR ONE | | | | |

TOLERANCES UNLESS OTHERWISE SPECIFIED
ON MACHINE SURFACES
2 DECIMAL PLACES ±0.01 INCH
3 DECIMAL PLACES ±0.005 INCH
WHOLE NUMBERS OR FRACTIONS ±1/64 INCH
ANGLES ±15 MINUTES
ON OTHER SURFACES
SAW CUT ±1/16 INCH
MACHINE FLAME CUT ±1/16 INCH
FINISHES ARE RMS VALUES EXPRESSED IN MICRO-INCHES

REFERENCES

| | | |
|---|---|---|
| DATE 4-26-76 | 7' x 10' T.W.T. | DEPARTMENT OF NAVY |
| DRAWN ROK | C C TRANS-AIRFOIL MODEL | DAVID W. TAYLOR NAVAL SHIP RESEARCH & DEVELOPMENT CENTER |
| CHECKED | ASSEMBLY | CARDEROCK LAB. - BETHESDA, MD. 20084 |
| DESIGNED | SECTION DETAILS | ANNAPOLIS LAB. - ANNAPOLIS, MD. 21402 |
| REVIEWED [illegible] | | DTNSRDC NUMBER: E-3375-5 |
| APPROVED [illegible] DATE 5/4/76 | SCALE 1/1 | REVISION |

E-3375-5

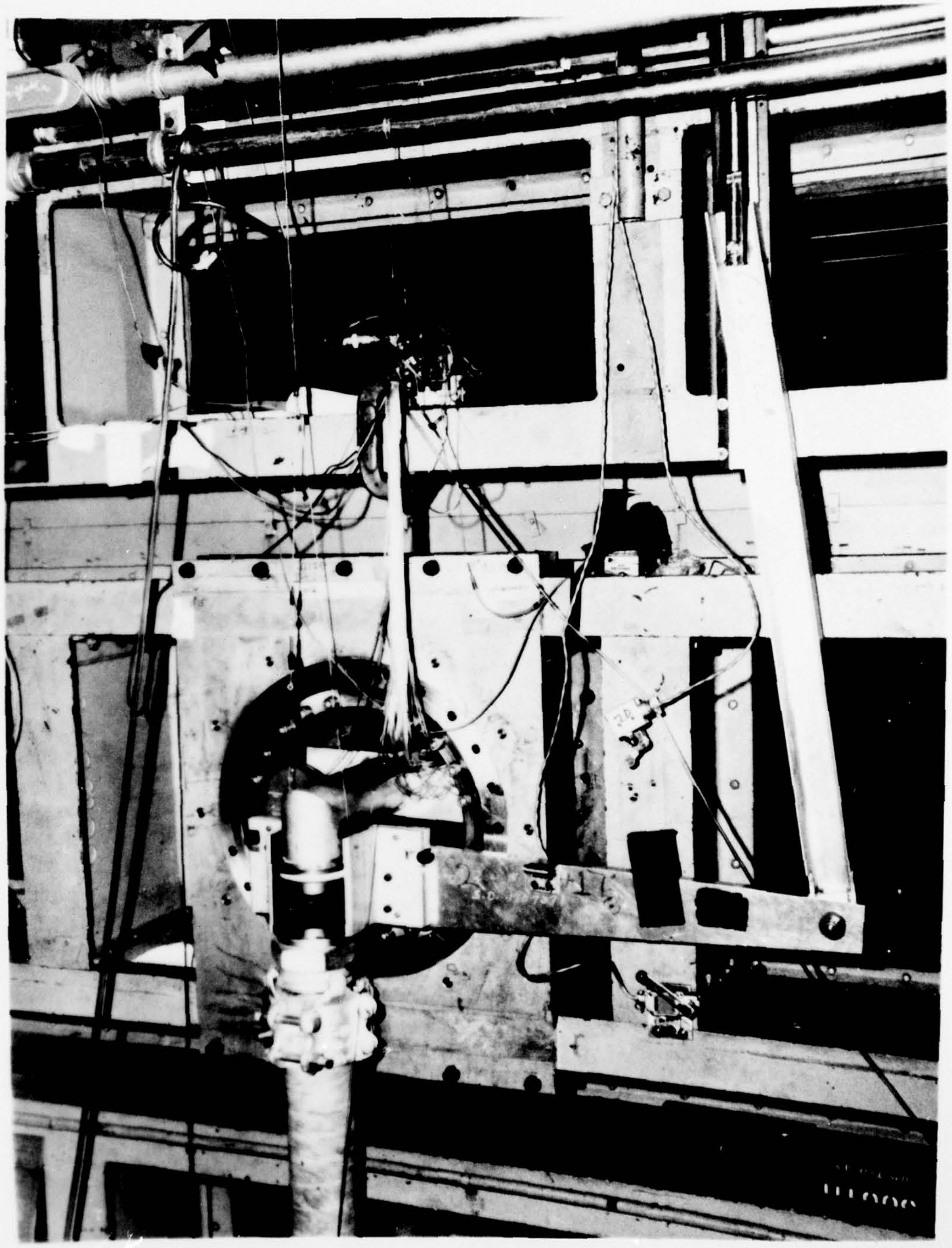
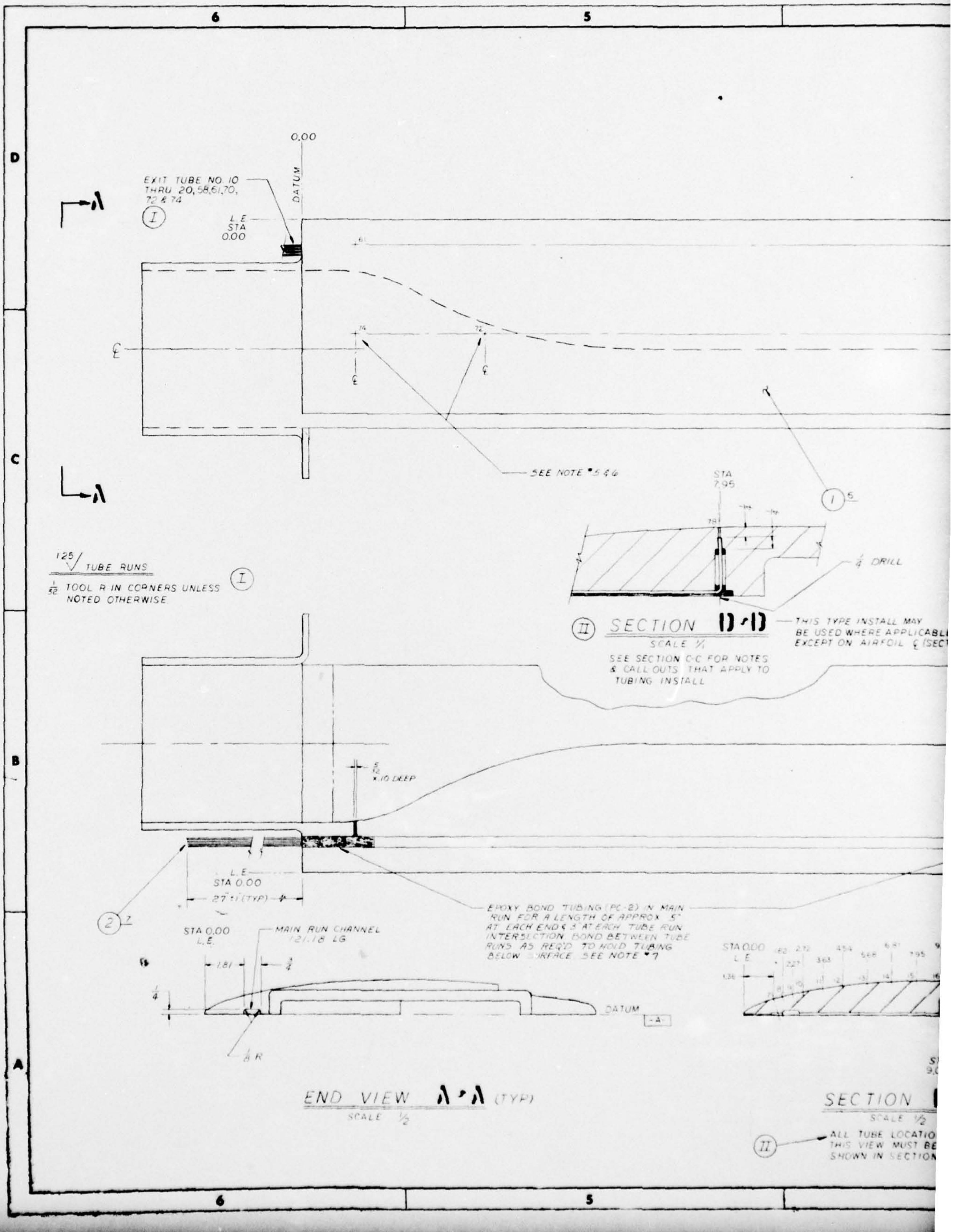
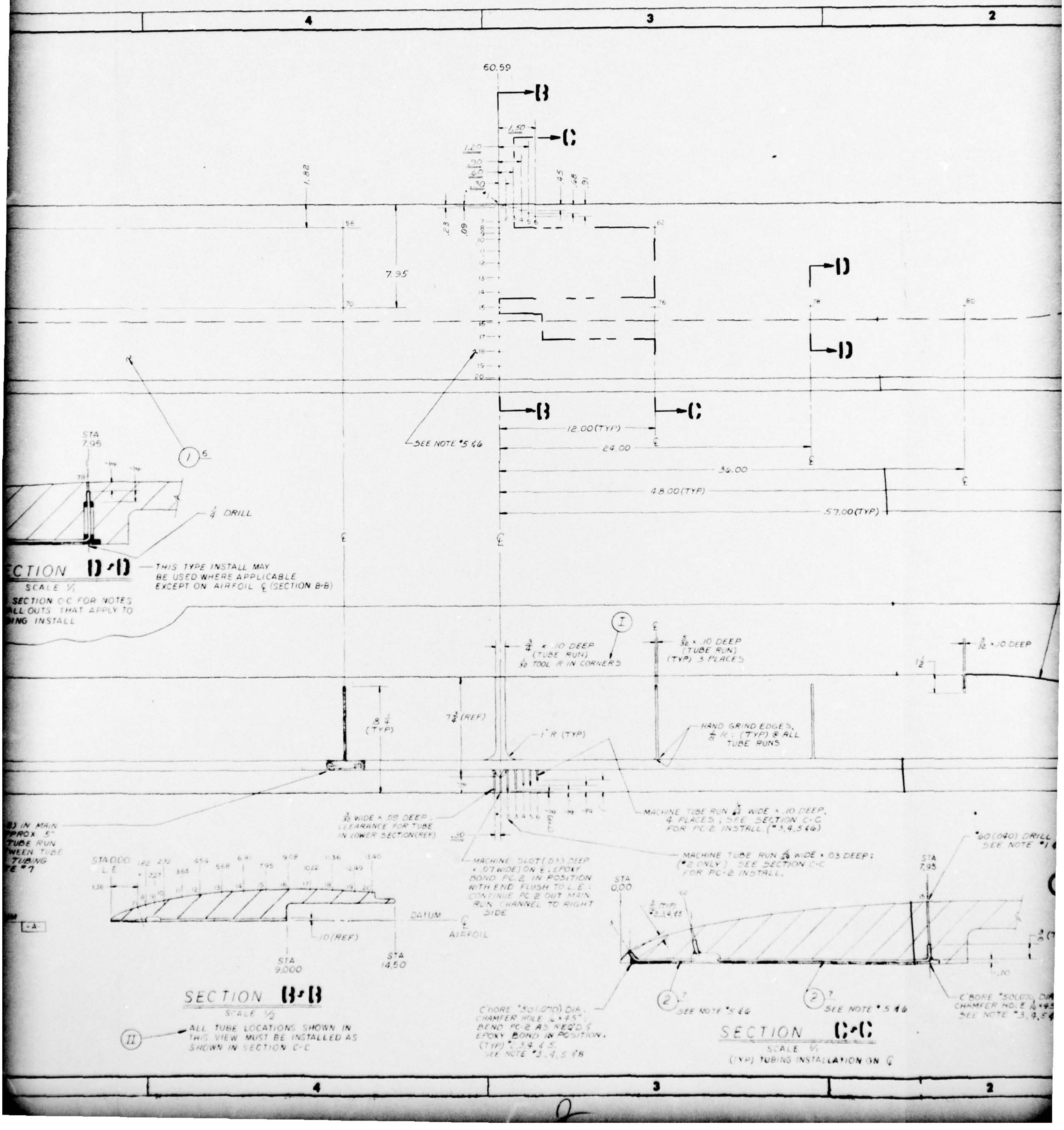


Figure 9 External Air Supply Connection and Pitch Angle Adjustment Actuator



EXIT TUBE NO 10 THRU 20, 58, 61, 70, 72 & 74
L.E. STA 0.00
DATUM
SEE NOTE 5 & 6
125 TUBE RUNS
1/32 TOOL R IN CORNERS UNLESS NOTED OTHERWISE
SECTION D-D
SCALE 1/1
THIS TYPE INSTALL MAY BE USED WHERE APPLICABLE EXCEPT ON AIRFOIL ℄ (SECT
SEE SECTION C-C FOR NOTES & CALL OUTS THAT APPLY TO TUBING INSTALL
1/4 DRILL
STA 7.95
.10 DEEP
EPOXY BOND TUBING (PC-2) IN MAIN RUN FOR A LENGTH OF APPROX 5" AT EACH END & 3" AT EACH TUBE RUN INTERSECTION. BOND BETWEEN TUBE RUNS AS REQ'D TO HOLD TUBING BELOW SURFACE. SEE NOTE 7
MAIN RUN CHANNEL 121.18 LG
STA 0.00 L.E.
1/8 R
END VIEW A-A (TYP)
SCALE 1/2
SECTION
SCALE 1/2
ALL TUBE LOCATIO THIS VIEW MUST BE SHOWN IN SECTION



SECTION D-D
SCALE 1/1
THIS TYPE INSTALL MAY BE USED WHERE APPLICABLE EXCEPT ON AIRFOIL ℄ (SECTION B-B)
SEE NOTE *5 & 6
12.00 (TYP)
24.00
36.00
48.00 (TYP)
57.00 (TYP)
HAND GRIND EDGES, 1/8 R (TYP) @ ALL TUBE RUNS
MACHINE TUBE RUN 1/4 WIDE × .10 DEEP, 4 PLACES; SEE SECTION C-C FOR PC-2 INSTALL. (*3,4,5 & 6)
MACHINE TUBE RUN 3/8 WIDE × .03 DEEP; (*2 ONLY) SEE SECTION C-C FOR PC-2 INSTALL.
MACHINE SLOT (.033 DEEP × .07 WIDE) ON ℄. EPOXY BOND PC-2 IN POSITION WITH END FLUSH TO L.E.; CONTINUE PC-2 OUT MAIN RUN CHANNEL TO RIGHT SIDE
SECTION B-B
SCALE 1/2
ALL TUBE LOCATIONS SHOWN IN THIS VIEW MUST BE INSTALLED AS SHOWN IN SECTION C-C
C'BORE .50 (.070) DIA. CHAMFER HOLE 1/16 × 45°. BEND PC-2 AS REQ'D & EPOXY BOND IN POSITION. (TYP) 2,3,4 & 5. SEE NOTE *3,4,5 & 8
SECTION C-C
SCALE 1/1
(TYP) TUBING INSTALLATION ON ℄
SEE NOTE *5 & 6

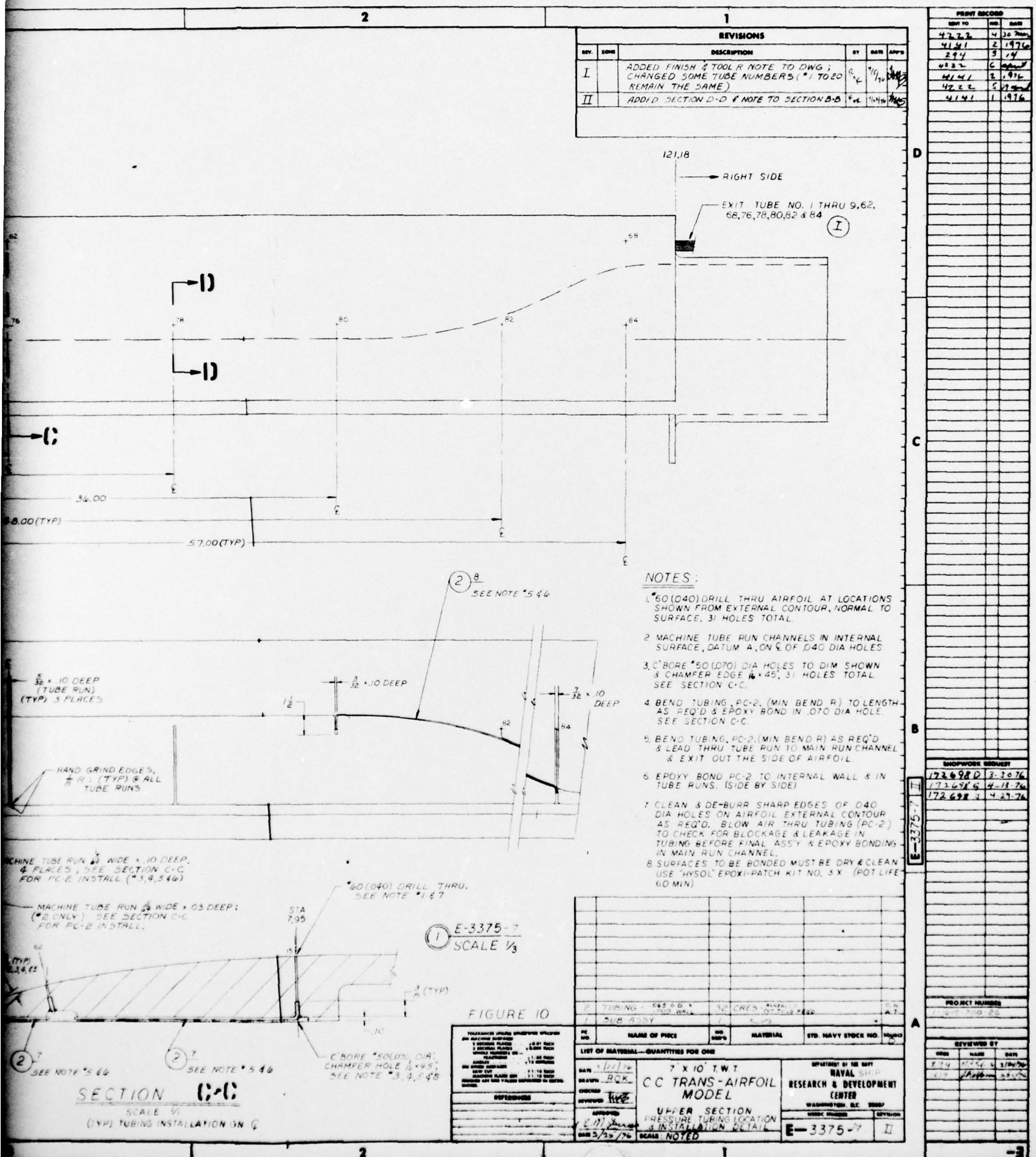

REVISIONS
I ADDED FINISH & TOOL R NOTE TO DWG; CHANGED SOME TUBE NUMBERS (#1 TO 20 REMAIN THE SAME)
II ADDED SECTION D-D & NOTE TO SECTION B-B
PRINT RECORD
SHOPWORK REQUEST
121.18
RIGHT SIDE
EXIT TUBE NO. 1 THRU 9, 62, 68, 76, 78, 80, 82 & 84
D
C
B
A
34.00
38.00 (TYP)
57.00 (TYP)
SEE NOTE #5 & 6
3/32 x .10 DEEP (TUBE RUN) (TYP) 3 PLACES
HAND GRIND EDGES, 1/8 R. (TYP) @ ALL TUBE RUNS
MACHINE TUBE RUN 3/32 WIDE x .10 DEEP, 4 PLACES, SEE SECTION C-C FOR PC-2 INSTALL (#3,4,5 & 6)
MACHINE TUBE RUN 3/32 WIDE x .03 DEEP; (#2 ONLY) SEE SECTION C-C FOR PC-2 INSTALL.
#60 (.040) DRILL THRU, SEE NOTE #1 & 7
STA 7.95
C'BORE #50 (.070) DIA, CHAMFER HOLE 1/16 x 45°, SEE NOTE #3, 4, 5 & 8
SECTION C-C
SCALE 1/1
(TYP) TUBING INSTALLATION ON ℄
E-3375-7
SCALE 1/3
NOTES:
1. #60 (.040) DRILL THRU AIRFOIL AT LOCATIONS SHOWN FROM EXTERNAL CONTOUR, NORMAL TO SURFACE. 31 HOLES TOTAL.
2. MACHINE TUBE RUN CHANNELS IN INTERNAL SURFACE, DATUM A, ON ℄ OF .040 DIA HOLES.
3. C'BORE #50 (.070) DIA HOLES TO DIM SHOWN & CHAMFER EDGE 1/16 x 45°, 31 HOLES TOTAL. SEE SECTION C-C.
4. BEND TUBING, PC-2, (MIN BEND R) TO LENGTH AS REQ'D & EPOXY BOND IN .070 DIA HOLE. SEE SECTION C-C.
5. BEND TUBING, PC-2, (MIN BEND R) AS REQ'D & LEAD THRU TUBE RUN TO MAIN RUN CHANNEL & EXIT OUT THE SIDE OF AIRFOIL.
6. EPOXY BOND PC-2 TO INTERNAL WALL & IN TUBE RUNS. (SIDE BY SIDE)
7. CLEAN & DE-BURR SHARP EDGES OF .040 DIA HOLES ON AIRFOIL EXTERNAL CONTOUR AS REQ'D. BLOW AIR THRU TUBING (PC-2) TO CHECK FOR BLOCKAGE & LEAKAGE IN TUBING BEFORE FINAL ASS'Y & EPOXY BONDING IN MAIN RUN CHANNEL.
8. SURFACES TO BE BONDED MUST BE DRY & CLEAN. USE "HYSOL" EPOXI-PATCH KIT NO. 3X (POT LIFE 60 MIN)
2 TUBING - .065 O.D. x .005 WALL 32 CRES - ANNEALED
1 SUB ASSY 1
PC NO. NAME OF PIECE NO. REQ'D MATERIAL STD. NAVY STOCK NO.
LIST OF MATERIAL—QUANTITIES FOR ONE
DATE 3/22/76 DRAWN RQK
7' X 10' T.W.T.
CC TRANS-AIRFOIL MODEL
UPPER SECTION PRESSURE TUBING LOCATION & INSTALLATION DETAIL
SCALE: NOTED
DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH & DEVELOPMENT CENTER
WASHINGTON, D.C.
E-3375-7 II
PROJECT NUMBER
REVIEWED BY

FIGURE 10

Figure 11  Lower Half of Airfoil Model Showing Rounded Trailing Edge and Angle of Attack Indicator

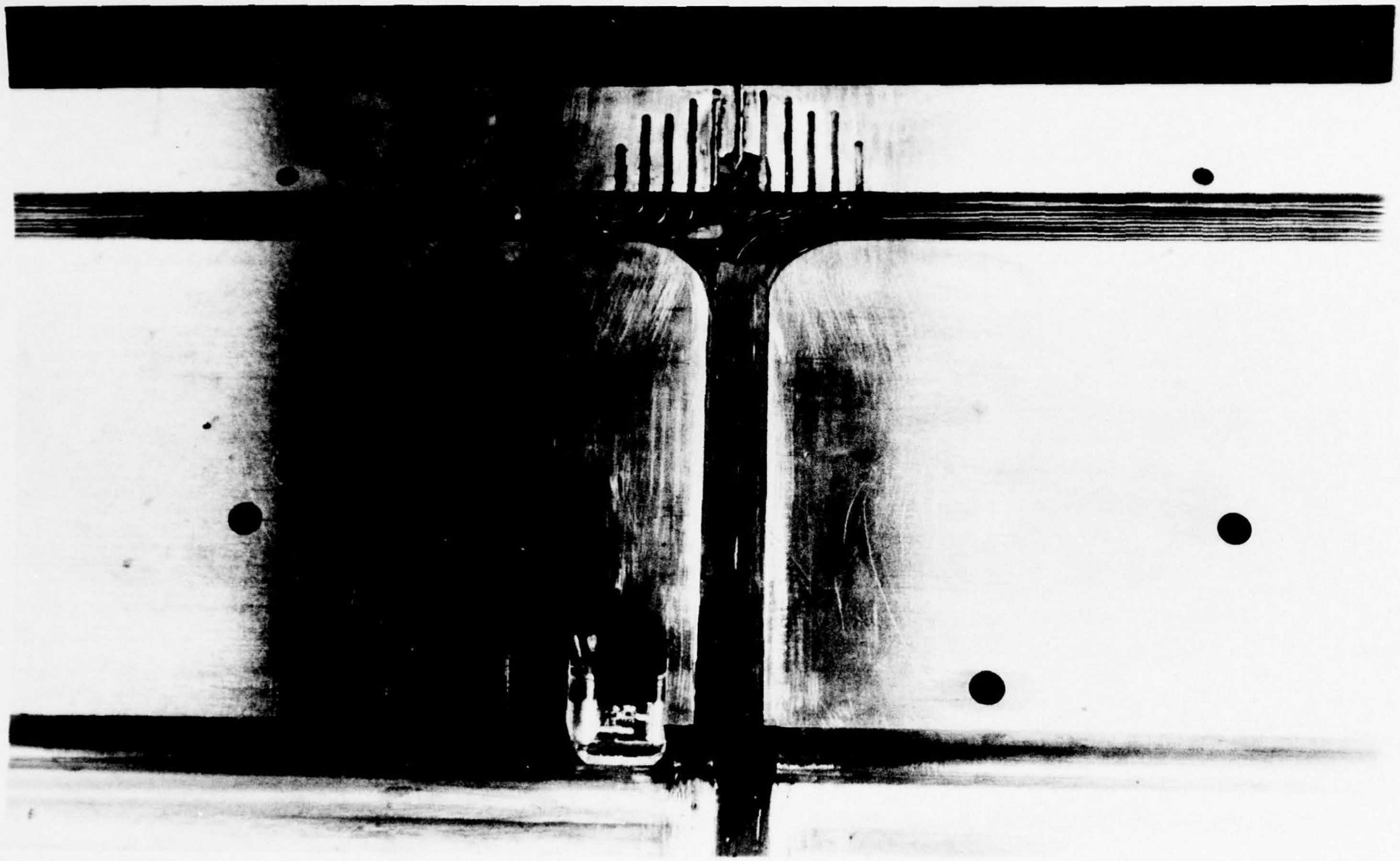


Figure 12  Tubing Installation in Leading Edge of Upper Half of Airfoil Model

TABLE 1 - SUMMARY OF COMPUTED STRESSES OR LOADS ON MAJOR ELEMENTS

| | | | Factor of Safety |
|---|---|---|---|
| 1. | Maximum Bending Stress in Airfoil (at strut attachment) | 9945 $lbf/in^2$ (68.57MPa) | 6.5 |
| 2. | Maximum Torsional Shear Stress (at mid-span) | 4419 $lbf/in^2$ (30.47MPa) | 8.4 |
| 3. | Maximum Bending Stress in Knife-Edge | 2453 $lbf/in^2$ (16.91MPa) | 26 |
| 4. | Maximum Vertical Force on End Supports (Airfoil) | 689 lbf (3.06KN) | 5.6 |
| 5. | Maximum Horizontal Shear Force on Interface of Airfoil Halves | 102,978 lbf (458KN) | 4 |
| 6. | Maximum Compressive (buckling) Force on Strut | 4400 lbf (19.57KN) | 9.6 |
| 7. | Maximum Tensile Force on Strut | 5611 lbf (24.96KN) | 14.3 |
| 8. | Deflection at Trailing Edge of Knife (between 3 inches (7.67 cm) centers of slot gap adjusting screws) | .0007 inches (17.78μm) | ---- |

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